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Comparison of Take Off Kinematics During Loaded Countermovement Jumps in Division One Female Gymnasts and Soccer Athletes

By

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A Plan B Project submitted in partial fulfillment
of the requirements for the degree of

Master of Science

in

Health and Human Movement

Approved:

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ABSTRACT

Purpose: The purpose of this study was to compare takeoff kinematics of incrementally loaded countermovement jumps (CMJ) in water and land in female gymnasts and soccer athletes. **Methods:** 24 Division I student athletes (12 gymnastics, 12 soccer) volunteered for this study. Subjects performed CMJ on land and water at a level of the xiphoid process without an arm swing. CMJs with loads of body weight (BW), 10% BW, 20% BW, and 30% BW were performed three times per trial at each load. 15 kinematic variables related to the lower extremity were examined. **Results:** For environment, significant ($p<0.001$) segment ROM values were greater on land than in water. Segmental velocities displayed mixed results, as thigh positive (countermovement) velocities were greater in water than land, and shank positive velocities were greater on land than water. During propulsion, all segmental velocities displayed significant ($p<0.001$) differences that were greater on land than water. For sport, gymnasts displayed greater ($p<0.001$) ROM values compared to soccer, with foot ROM exhibiting the greatest difference at 22.1 ± 2.3° (mean ± SD). In the propulsive phase, gymnasts displayed 23.3 ± 3.7° greater plantarflexion than their soccer counterparts. Segmental velocities of the foot followed suit with gymnasts' findings relating to the foot velocity were greater by 103 °/second. Physical properties of water, specifically buoyancy and drag, played a vital role in environmental differences. When comparing sport, gymnasts displayed greater foot ROM likely due to the aesthetic aspect of gymnastics compared to soccer in regards to improving an athlete's score based on how well the gymnast can "point their toes" during competition. No significant findings were identified by the effect of load on both environment and sport. **Conclusion:** These results suggest the

buoyancy of water may facilitate the countermovement phase yet the extensive drag forces during propulsion restrict segmental velocities during propulsion.

INTRODUCTION

A countermovement jump (CMJ) has been established as reliable measure of multijoint dynamic strength and neuromuscular power in the lower extremity (Markovic, Dizdar, Jukic, & Cardinale , 2004; Myer, Ford, Palumbo, & Hewett, 2005; Nuzzo, McBride, Cormie, McCaulley, & Grant, 2008). Kinematic joint contributions during a countermovement jump have been established as factors in determining vertical jump performance (Alexander, 1990; Bobbert, Mackay, Schinkelshoek, Huijing, & van Ingen Schenau, 1986; Feltner, Bishop, & Perez, 2004; McErlain-Naylor, King, & Pain, 2014). The use of aquatic training and therapy is becoming an accepted practice in the world of athletics and physical rehabilitation (Becker 2009; Martel, Harmer, Logan, & Parker, 2005; Stemm & Jacobson, 2007). However, there is an overwhelming gap in the literature pertaining to joint kinematics of aquatic training and therapy.

In several studies, a CMJ has been shown to correlate with measures of muscular strength and power. In a study testing the one repetition maximum (1RM) of squat and power clean, 1RM strength test has been shown to be correlated with results of the CMJ with relative CMJ peak power, CMJ peak velocity, and CMJ height (Nuzzo et al., 2008). Twelve Division one athletes (seven football players, 6 track and field athletes) participated in the study. Two separate testing sessions were performed at least four days apart; with 1RM squat and power clean completed as the first session. CMJ and single-joint isometric testing (ISO) were performed in the second testing session at least four days apart. ISO strength tests were not correlated with CMJ performance.

Along with the squat jump (SJ), a CMJ is the most reliable and valid test for the estimation of explosive power in physically active men (Markovic et al., 2004). In a study of 93 healthy college-aged men, the reliability and validity of seven jump tests were examined. The SJ and CMJ were shown to be the most valid and reliable measures of explosive power in physically active males. In a study of 53 female high school athletes, a modified CMJ was used as a test of vertical jump height during a neuromuscular strength-training program (Myer et al., 2005).

Kinetic joint variables, specifically peak propulsive power (PP), have been established as a determinant of athletic performance and training (Cronin & Sleiver, 2005). Joint contributions for jump tests have also been studied, with the hip, knee, and ankle joints accounting for 38%, 32%, and 30% of total work during the push-off phase of the CMJ (Bobbert et al., 1986). ROM is also a factor of jump performance, as Alexander (1990) studied the kinematic variables for high and long jumpers. He found that the mean knee angle of the athletes he studied was 45º when the athletes' leg was set down in preparation for the jump. Another study displayed how a deeper squat position increased jump height performance (Gheller et al. 2015; Moran & Wallace, 2007). Velocity (velocity=displacement/time) of center of mass (CM) was also studied, and the use of an arm swing contributed to an increase of CM velocity, which in turn increased jump height (Feltner et al., 2004). In the same study, CM velocity was described as the summation of segment velocities in the lower extremity. Therefore, along with PP, joint angles and segmental velocities can be considered determinants of jump performance.

Aquatic training and therapy has seen a rise in popularity as of late, but remains an underutilized form of training and rehabilitation. In rehabilitation, buoyancy plays a vital role in return to normal strength, as 60% or more of body weight (BW) may be offloaded while immersed at the level of the Xiphoid process, thus decreasing impact forces upon landing (Becker 2009). Donoghue, Shimojo, and Takagi (2011) studied how impact forces were affected by submersion at about three centimeters below the Xiphoid process compared to land. 18 male participants performed ankle hops, tuck jumps, a CMJ, and single-leg vertical jump were performed on both land and in water. Peak impact forces, impulse, and rate of force development were decreased by up to 62% as compared to land. Due to the reduction of impact forces during plyometric landing in water compared to land, it is theorized that aquatic training may decrease the risk of injury occurrence while also maintaining similar results in performance when compared to land (Stemm & Jacobson, 2007). Louder, Searle, and Bressel (in press) support the aforementioned benefits of aquatic training, citing physical properties of water (buoyancy, fluid resistance, and hydrostatic pressure) as key factors in the application of aquatic plyometric training as an alternative to land-based plyometric training. Buoyancy and drag forces are especially crucial factors in aquatic training and therapy, as these properties decrease apparent mass and increase load, respectively (Becker 2009; Louder et al., in press; Triplett et al., 2009).

The benefits of aquatic training and rehabilitation have been previously established (Becker 2009; Stemm & Jacobson, 2007). Kinematic differences in land and water between college-aged male subjects have also been recorded, as incrementally loaded CMJ in water displayed an increase in PP and mean power (MP) compared to land (Nardoni 2015). There remain two main gaps in the literature when discussing take off kinematics of a CMJ. The first is jump kinematic values in an aquatic environment.

Several studies have examined joint kinematics on land (Alexander, 1990; Bobbert et al., 1986; Feltner, Bishop, & Perez, 2004; McErlain-Naylor et al., 2014), but there are no studies to our knowledge that have examined joint kinematics in water. The second gap is assessing kinematic differences between female gymnasts and soccer players at the collegiate level. Research in our own laboratory has displayed greater take off PP and MP in water when compared to land in female gymnasts and soccer players, with differences in kinetic values between the two populations (Gollofon 2016).

The purpose of this study is to compare takeoff kinematics of incrementally loaded CMJs in water and land in female gymnasts and soccer athletes. This study will have three hypotheses; 1) There will be a significant difference between gymnasts and soccer players' kinematic variables; 2) Segment angular velocities and joint ROM will decrease as load increases; 3) Segment angular velocities and joint ROM will be significantly different in water immersion vs. land.

METHODS

Twenty-four Division I female student athletes from Utah State University volunteered for this study. Subjects were aged 18-22 years of age and were recruited from the gymnastics (n = 12) and soccer (n = 12) teams. All subjects required two criteria to be met; 1) Self-reported as orthopedically healthy and 2) No surgeries within the last three months so they could perform the loaded countermovement jumps safely. All subjects signed an informed consent form and were notified of the requirements to perform the study. The Institutional Review Board approved procedures and the informed consent form.

PROCEDURES

Subjects performed a countermovement jump (CMJ) on land and in water at a level of the xiphoid process. CMJ's were performed at body weight (BW) and with loads equal to 10, 20 and 30% BW. Three trials were completed for each condition. An acceptable trial was performed when subjects' hands remained on their hips throughout the entirety of the jump and both feet landed simultaneously on the force plate. Jumps that did not meet these criteria were repeated.

Each condition was performed on an adjustable-depth underwater treadmill (HydroWorx 2000; Middletown, Pa). Land jumps were performed with the HydroWorx treadmill set above water depth

All jumps were recorded using a GoPro Hero 4 camera (GoPro Inc.; San Mateo, CA) in the sagittal plane. Video was recorded at 120 frames/second. The camera was placed on a plyometric jump box at approximately knee height of the subject for all land jumps. For underwater jumps, the camera was placed at a comparable height on a sidewall of the HydroWorx underwater treadmill using a suction cup mount and waterproof case. Recording began when a preparatory command was given to the subject and ended when the subject returned to a pre-jump state on the force plate following the CMJ.

Loading conditions of subjects were performed using a weighted vest (MIR Vest Inc; San Jose, CA). Percentage of body weight was rounded to 1.4 kg (3 pounds) increment for each loaded condition (10%, 20%, and 30%). A rest period of 2-3 minutes occurred between each condition as weights were removed or added to the vest.

DATA PROCESSING

Video files from the camera were processed using Logger Pro software (Vernier Software & Technology; Beaverton, OR). Scale and orientation of each individual trial were performed prior to digitization of anatomical landmarks. Four anatomical landmarks of the left hip, knee, ankle, and foot were used for processing of takeoff kinematics; 1) greater trochanter of the femur, 2) lateral epicondyle of the femur, 3) lateral malleolus of the fibula, and 4) base of the fifth metatarsal. Video digitization started immediately before the subject began the CMJ and continued throughout loading and propulsion.

ROM and segment angular velocities for both loading and propulsion phases of the jump were calculated for the thigh, shank, and foot. Peak velocities for loading and propulsive phases were represented by positive and negative values, respectively. Data was then transferred to Microsoft Excel (Microsoft Corp.; Redmond, WA) for analysis.

STATISTICAL ANALYSIS

All variables were analyzed with a 3-Way (2, Sport) x 2 (Environment) x 4 (Load) Repeated Measures ANOVA). When necessary, post hoc analyses were completed using the LSD test. The level of confidence was set at $p<0.05$.

RESULTS

ROM

The repeated measures ANOVA revealed thigh ROM (tROM) was significantly greater on land vs water ($p<0.001$) with a difference of $3.6 \pm .9°$. A significant main effect for Shank ROM (sROM) ($p<0.001$) and Foot ROM (fROM) ($p<0.001$) for sport was identified, with gymnasts having a greater sROM and fROM of $4.93 \pm 3.7°$ and $22.1 \pm 2.3°$, respectively. Load did not have a significant effect ROM.

Countermovement Phase- There was a significant main effect for environment thigh minimum ROM (tMIN), shank minimum ROM (sMIN), and foot minimum ROM (fMIN) at p=.002, p=.016, and p<.001, respectively. Land was significantly greater than water during thigh and shank flexion and foot dorsiflexion during the countermovement phase of the jump. A significant main effect for sport was also identified (p<.001). Gymnasts displayed greater sMIN than Soccer athletes with a mean difference of 7.8 ± .7. A significant interaction for Environment*Sport was identified in sMIN (p=.001) as Soccer athletes completed less shank flexion (-2.1 ± .1° degrees) in water compared to land while Gymnasts completed shank flexion that were essentially identical (.3 ± .1° degrees) in water vs land. There were no significant findings for the effect of load.

Propulsion Phase- The repeated measures ANOVA displayed a significant main effect with environment for thigh maximum ROM (tMAX) and shank maximum ROM (sMAX) at p<.001 and p=.004, respectively. Thigh and shank position at extension were significantly greater on land vs water. There was a mean difference of 1.2 ± .3° for tMAX and 1.8 ± .6° for sMIN. No significant main effect was reported (p=.536) for foot minimum ROM (fMIN). There was a significant effect for sport for tMAX and fMAX (p<.001), with tMAX soccer displaying greater values than gymnasts and fMAX gymnasts greater than soccer.. The greatest difference for sport was observed for fMAX with a mean difference of 23.3 ± 3.7°. No significant main effect occurred for load.

Segmental Velocity

Countermovement Phase- Maximum thigh positive velocity (tPOS) displayed a significant main effect for environment (p<.001). Means for tPOS were greater in water vs land by a difference of 28.3 ± 2.5 degrees per second (°/s). Maximum shank positive velocity (sPOS) was significantly greater ($p<0.001$) for gymnasts vs soccer athletes. There was a significant main effect for sport for fPOS ($p<0.001$). Soccer displayed greater fPOS with mean difference of 60.2 ± 5.2°/s compared to gymnasts.

A significant interaction between Environment*Sport existed for tPOS ($p=.004$) and fPOS ($p=.029$). In water, tPOS velocity was greater by 20.6 ± .5°/s for gymnasts and 35.9 ± .4°/s; for soccer athletes. For fPOS, gymnasts decreased by 12.6 ± 1.6 °/s in water compared to land while soccer athletes increased by 3.4°/s ± 1.5.

Propulsion Phase- Maximum thigh negative velocity (tNEG), maximum shank negative velocity (sNEG), and maximum foot negative velocity (fNEG) displayed significant main effects for environment with $p=.03$, $p<.001$, and $p=.002$, respectively. tNEG was 39.1 ± 7.7°/s, sNEG 11.3 ± 2.4°/s, and fNEG was 28.7 ± 6.0°/s greater on land vs water.

There was significant main effect between sport for tNEG ($p<.001$) and fNEG ($p=.004$). Soccer athletes displayed greater negative velocities than gymnasts for tNEG with mean difference of 107.9°/s ± 16.5. Conversely, gymnasts displayed greater negative velocities for fNEG by 103 °/sec. There was no significant main effect between sport for sNEG ($p=.212$). No significant main effect occurred for load.

DISCUSSION

The purpose of this study was to compare takeoff kinematics of incrementally loaded CMJs in water and land in female gymnasts and soccer athletes. There were significant differences when comparing environment. Significant differences also existed when comparing sport. No significant differences occurred when comparing the effect of incremental load on CMJ performance in both land and water.

Effect of Load

No significant main effect for load existed for all variables. A few variables approached the confidence level of $p<.05$, specifically tPOS ($p=.065$) and tNEG ($p=.083$). When examining the post hoc analysis of tPOS and tNEG, loads of 20% and 30% reached significance level. Gollofon (2016) reported similar results on land when examining peak propulsive power (PP) of the same subjects. There were no significant effects of incrementally increasing load for PP of subjects. This lack of significance could be explained by several reasons. The amount of weight needed for significance to be achieved may not have been enough in our study. If greater loads of 20% and 30% were close to reaching the set confidence level, increasing the load past 30% could conceivably increase significance of load for this study. Another reason could be the number of participants. Due to video capture and video quality, several subjects were removed from the study. In total, 8 Gymnasts and 11 Soccer remained. Perhaps adding more subjects could increase the likelihood of reaching significant values for effect on load.

CMJ on Land

The effects of ROM on CMJ performance have been studied by several authors (Alexander 1990; Gheller et al., 2015; Moran & Wallace, 2007), specifically knee flexion. In those previous studies, knee flexion greater than 90° (with 0° being full extension) was shown to increase jump performance in height (Gheller et al., 2015) The results from this study in terms of ROM (see tables 2 and 3) correlate with previous studies studying CMJ ROM kinematic parameters. There is very little literature regarding segment velocities during a CMJ. Feltner et al. (2004) reported Center of Mass (CM) velocity as an indicator of jump performance. An increase in CM would lead to an increase in jump height. They also described CM velocity as a resultant of several segments of the lower extremity (Feltner et al., 2004). While their study examined linear velocities in meters/second, this study looked at °/s for thigh, shank, and foot angular velocities (see tables 8-13).

In a study by McErlain-Naylor et al. (2014), three main parameters for determining CMJ height were established; 1) CMJ peak knee power, 2) Take-off shoulder angle 3) CMJ peak ankle power. When comparing this study with the current study, McErlain-Naylor et al. (2014) reported hip, knee, and ankle minimum angles during the countermovement phase at 75 ± 15°, 81 ± 16°, and 84 ± 9°, respectively. The current study displayed angles of 132 ± 8°, 94 ± 4, and 122 ± 9°. At takeoff, McErlain-Naylor et al. (2014) displayed 172 ± 5° for hip, 174 ± 14° for knee, and 137 ± 12° for ankle. For the current study, hip displayed 180 ± 4°, knee displayed 128 ± 3°, and ankle displayed 164 ± 21°. There are several reasons for such differences in countermovement and takeoff kinematics between our study and theirs. One is the lack of arm swing in our study. Feltner et al. (2004) studied the differences of segmental and kinetic contributions in vertical jumps with and without an arm swing.

Kinematic Comparison by Sport

One of the purposes of this study was to compare gymnasts and soccer players' kinematic variables during CMJ on land versus water. When comparing sport, there were significant main effects for sROM, fROM, tMAX, fMAX, and sMIN. For hip tMAX, the data from this study displayed greater hip extension for Gymnasts than Soccer (182.3° > 178.6°). This means that during the propulsive phase of the CMJ, Gymnasts were taking off with the hip with more extension and actually going past the normal ROM of 180°

into hyperextension. Soccer was below full extension at take off during the propulsive phase.

When observing knee angles, sROM and sMIN in Gymnasts displayed greater values than Soccer. In the countermovement phase, Gymnasts displayed deeper knee flexion (sMIN) at 90.0° compared to Soccer at 96.8°. The greatest contrast by sport between variables was that of the foot by sport. Gymnastics displayed greater fROM than Soccer with 53.47° and 31.35°, respectively. The majority of this difference occurred during plantarflexion (PF) of the foot during the propulsive phase of the CMJ. Gymnasts achieved a peak PF of 178.5° compared to 153.6° for Soccer. This is most likely attributed to the differences in sport performance. In soccer, large gross motor skills such as running and kicking using hand-foot coordination combined with rapid change of direction and accelerations require a skill set fairly common to many sports in general. Whereas in gymnastics, aesthetics is a critical component of score earned in each event. It is not uncommon during a gymnastics meet to hear a coach shout out instructions, "Point your toes!" Part of the judging is based off how well PF is achieved during routines, which is the most likely reason for the exaggerated Gymnasts' PF ROM. Additionally, gymnasts develop routines where through a series of jumps, bounds and tumbling sequences they may rely on PF for the majority of propulsion or translation achieved.

When comparing Gymnasts to Soccer in terms of segmental velocity, it is no surprise that Gymnast fNEG displayed greater velocity during PF compared to soccer due to previous findings with ROM. This, again, can be attributed to the greater PF that gymnasts as a whole attain to achieve during sport. Completing a greater ROM in the foot throughout the CMJ will require a greater velocity to complete the ROM in the time it takes to attain maximal PF during the propulsive phase.

Countermovement with Environment

The physical properties of water compared to air remained one of the main reasons this study was undertaken. One of the hypotheses was how environment might influence CMJ kinematics. Because the property of buoyancy in water would offload 65% of a person's body weight (Louder et al., in press), it may have influenced the results of this study. As subjects moved into the countermovement phase for tPOS, buoyancy may have facilitated this movement phase. However, the segmental velocities were greater on land, questioning this observation (Louder et al., in press). Drag forces also affected subjects performing a CMJ, as they rise during the propulsive phase with an increase in jump speed in water in quadratic fashion (Louder et al., in press; Triplet et al., 2009).

A concept that might explain why water immersion displayed decreased ROM values is that of lightening during the countermovement phase in an aquatic environment (Louder et al., in press). Louder et al. (in press) described the length and proportion of time spent in the lightening phase was greater in water than land due to buoyancy. They described how buoyancy produces a more superior center of gravity, causing greater instability and a need to correct the instability while performing the countermovement. Along with instability, the upward acceleration of buoyancy may cause more pronounced kinematic observations such as a heel lift more pronounce when compared to land. There were several significant main effects for environment, with tROM, tMAX, tMIN, sMAX, sMIN, and fMIN all having significant main effects for ROM. In all instances, land displayed greater ROM than in water. One theory for such differences in land vs water is due to subjects' deliberate adjustment of the countermovement phase. Subjects may have avoided a deeper countermovement phase to avoid submersion of the head in water. As previously stated, the property of buoyancy may have played a role in the ROM differences. With the countermovement phase being easier in water due to buoyancy, less deep flexion of the hip, knee, and dorsiflexion (DF) of the foot were required to generate the needed force for the transition to the propulsive phase.

Propulsion with Environment

Segmental velocity for tNEG and fNEG displayed significant main effects for environment. In both instances, land velocity was significantly greater. This difference can most likely be due to drag forces of water. While buoyancy may offload the weight of the body at the level of the xiphoid process, the effect of drag may offset buoyancy due to the increase of resistance as speed of jumping concurrently increases (Hamill & Knutzen, 2006; Triplett et al., 2009). Gollofon (2016) reported greater PP in water compared to land. The results of the current study displayed lower peak segmental velocities, suggesting kinematic factors may not be as good of predictors of jump performance as PP.

Differences between the current study and previous studies (Gheller et al., 2015; McErlain-Naylor et al., 2014) could also be explained by the experience level of the subjects performing the CMJ. Gheller et al. (2015) described how greater knee flexion during the countermovement phase might correlate with jump performance. However, McErlain-Naylor et al. (2014) reported that experience plays a vital role in jump performance when a deeper countermovement is attained. They explained how only experienced jumpers might display an increase in jump performance with greater knee and ankle ROM. As recommended by Feltner et al. (2004) further investigation is necessary to understand the complex, multisegmental dynamics and possibly altered muscular recruitment patterns that allows the arm swing to facilitate the production of extension torques at the hip, knee, and ankle during the propulsive phase (Vanezis & Lees, 2005). Rate of force development is also suggested as a predictor of jump performance and needs to be investigated further (Feltner, 2004; Laffaye & Wagner, 2013). There may also be varied effects of an arm swing based on participants' proficiency or skill level.

The movement of the foot during the countermovement phase may have also affected foot velocity. While performing the countermovement, several subjects visually displayed a "hitch" in movement. On land, all subjects' heel remained firmly planted on the force platform in during the countermovement phase and lifted during the propulsive phase. In water trials, the heel lifted during the countermovement phase and then returned to starting position immediately prior to the propulsive phase. The propulsive phase did not visibly change in water compared to land. This could be a reason for a significant difference in foot velocity. Perhaps this a unique technique adopted by the majority of the subjects in the study to adapt to added buoyancy during the CMJ. Further studies at shallower water depths at hip or mid thigh should be conducted to examine this observation.

Limitations

There were several limitations to this study. The subjects in the study were all female Division I gymnasts and soccer athletes, and results cannot be assumed for other populations. Skill level was also a factor, as subjects were not skilled at performing a CMJ in the aquatic environment. Along with unfamiliarity of performing a CMJ in water, variance in the jump itself may have been a limitation to the study. Subjects were instructed to “jump as high as possible using your natural jumping method”. Not all subjects were required to bend as deeply as others, or between trials. Self-perceived effort may have also been a limiting factor. For reasons beyond the control of the study, subjects may have just been “going through the motions” while performing jumps. Some key reasoning for this may have been time of the day, week, or which part of the season each sport was in. At the time of the study gymnastics was currently in season while soccer was in the offseason, which leads to another limitation. Muscle fatigue for both sports may have been present, albeit for different reasons. Gymnasts may have experienced fatigue due to the rigors of competition, while soccer has a more difficult lifting regiment in the offseason.

Equipment used in the study was also a limitation, as the weighted vest was limited to 1.4 kg increments. While loads were not exact percentage of BW, the load was within 1.3% of the desired weight. The vest was also attached to the body at the upper torso, which is an unusual distribution of weight for a normal human being. Drag force may have also been increased due to the vest, as it created an uneven surface area covering the upper torso. Continuing with equipment limitations, video data for several subjects was lost due to poor video quality in water or recording start time of the video camera. In total, four Gymnasts and one Soccer were lost due to incomplete or poor video data. Because of poor video quality in water, several video files made anatomical landmarks difficult to identify, which may have lead to less accurate measures of data collection.

Future research should focus on reproducing the methods of this study using depth jump and squat jump. Comparing male sport participants (gymnasts and soccer athletes) should also be investigated. As previously mentioned, a decreasing in water depth and increase in weight (> 30% BW) should be examined in the future to discover the effects of such variations on jump kinematics. Developing ensemble curves to evaluate coordination among body segments should also be investigated. Finally, correlating kinematic data with force data is essential in creating a link with the kinetics and kinematics of jumping on performance.

CONCLUSION

When comparing by sport, Gymnasts displayed greater ROM differences than Soccer. Gymnasts also displayed greater segmental velocities, with foot velocities correlating with its ROM counterpart. The effect of environment also had several significant differences, as land trials displayed greater ROM and segmental velocities. This is likely due to the physical properties of water, namely buoyancy and drag force in an aquatic environment. No significant differences existed when comparing loads. Increase load beyond 30% BW for future studies may be necessary in establishing significant findings for load. In addition, the properties of water may serve as an adjunct training environment for athletes who want to add to training without added stress of full BW training.

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Table 1: Descriptive Statistics for Subjects (mean ± SD)

Sport	N	Age	Height (cm)	Mass (kg)	Years of College Experience
Gymnastics	8	19.9 ± 1.1	160.7 ± 7.9	62.2 ± 6.7	1.4 ± 1.2
Soccer	11	19.8 ± 1.0	166.2 ± 4.8	64.6 ± 6.9	1.3 ± 0.7

Table 2: Peak thigh flexion and extension (mean degrees ± SD) on land

Condition	Sport	Load	Range	Flexion	Extension
Land	Gymnast	BW	46.89 ± 7.47	132.26 ± 7.47	183.28 ± 2.23
		10%	49.22 ± 11.27	132.82 ± 11.27	182.03 ± 2.49
		20%	48.98 ± 9.87	132.78 ± 9.87	181.75 ± 2.73
		30%	48.9 ± 9.98	133.33 ± 9.98	182.18 ± 3.04
		Total	48.53 ± 9.28	133.05 ± 9.28	182.32 ± 2.58
	Soccer	BW	48.09 ± 9.59	131.01 ± 9.59	179.93 ± 4.18
		10%	46.34 ± 9.40	131.20 ± 9.40	178.06 ± 4.27
		20%	47.49 ± 6.41	130.91 ± 6.41	177.23 ± 2.77
		30%	46.83 ± 6.13	131.48 ± 6.13	176.57 ± 3.43
		Total	47.22 ± 7.85	131.14 ± 7.85	178.60 ± 3.69
	Total	BW	47.63 ± 8.61	131.96 ± 8.61	181.42 ± 3.78
		10%	47.52 ± 9.97	131.86 ± 9.97	179.80 ± 4.04
		20%	48.15 ± 7.90	131.74 ± 7.90	179.96 ± 3.19
		30%	47.8 ± 7.97	132.30 ± 7.92	179.70 ± 3.98
		Total	47.78 ± 8.45	131.97 ± 8.45	180.23 ± 3.74

Table 3: Peak thigh flexion and extension values (mean degrees ± SD) on land

Condition	Sport	Load	Range	Flexion	Extension
Water	Gymnast	BW	44.44 ± 4.79	134.34 ± 4.79	181.46 ± 1.50
		10%	46.62 ± 4.80	135.72 ± 4.80	180.80 ± 1.98
		20%	45.22 ±5.57	135.39 ± 5.57	180.60 ± 1.77
		30%	46.56 ± 4.73	135.08 ± 4.73	181.64 ± 1.82
		Total	45.72 ± 4.82	135.11 ± 4.82	181.13 ± 1.73
	Soccer	BW	42.67 ± 10.51	134.31 ± 10.50	177.93 ± 3.19
		10%	41.84 ± 10.59	134.43 ± 10.59	177.19 ± 3.76
		20%	42.42 ± 10.45	133.50 ± 10.45	176.98 ± 2.51
		30%	43.92 ± 9.27	133.51 ± 9.27	177.14 ± 2.92
		Total	42.68 ± 9.88	134.19 ± 9.88	177.33 ± 3.02
	Total	BW	43.36 ± 8.59	134.33 ± 8.59	179.50 ± 3.10
		10%	43.81 ± 8.81	134.96 ± 8.81	178.77 ± 3.54
		20%	43.66 ± 8.52	134.34 ± 8.52	178.69 ± 2.83
		30%	45.16 ± 7.39	134.76 ± 7.39	179.26 ± 3.33
		Total	43.98 ± 8.20	134.60 ± 8.20	179.07 ± 3.15

Table 4: Peak shank flexion and extension values (mean degrees ± SD) on land

Condition	Sport	Load	Range	Flexion	Extension
Land	Gymnast	BW	36.39 ±3.94	90.22 ±3.06	127.61 ± 2.60
		10%	37.89 ± 3.81	90.31 ± 3.49	127.80 ± 2.26
		20%	37.40 ± 4.42	90.19 ± 3.07	128.43 ± 3.35
		30%	36.42 ± 3.15	90.45 ± 3.08	126.95 ± 2.28
		Total	37.02 ± 3.67	90.29 ± 3.01	127.72 ± 2.61
	Soccer	BW	32.38 ± 5.59	96.88 ± 3.63	128.52 ± 2.68
		10%	31.68 ± 5.04	97.29 ± 2.83	128.30 ± 2.97
		20%	32.59 ± 4.07	96.35 ± 2.74	128.95 ± 3.30
		30%	31.59 ± 3.51	96.84 ± 2.64	127.27 ± 2.52
		Total	32.08 ± 4.52	96.84 ± 2.92	128.29 ± 2.84
	Total	BW	33.80 ± 5.31	94.08 ± 4.73	128.14 ± 2.61
		10%	34.23 ± 5.45	94.41 ± 4.65	128.10 ± 2.63
		20%	34.57 ± 4.75	93.61 ± 4.22	128.72 ± 3.23
		30%	33.86 ± 4.08	93.83 ± 4.29	127.13 ± 2.34
		Total	34.12 ± 4.83	93.98 ± 4.39	128.05 ± 2.74

Table 5: Peak shank flexion and extension values (mean degrees ± SD) in water

Condition	Sport	Load	Range	Flexion	Extension
Water	Gymnast	BW	37.71 ± 3.08	89.58 ± 1.89	129.01 ± 4.77
		10%	39.19 ± 4.85	89.80 ± 1.84	128.08 ± 4.69
		20%	38.74 ± 6.02	89.38 ± 4.09	130.12 ± 5.67
		30%	38.02 ± 5.12	91.03 ± 3.35	128.42 ± 5.35
		Total	38.43 ± 4.71	89.96 ± 2.91	128.98 ± 4.95
	Soccer	BW	33.03 ± 8.67	98.77 ± 4.13	130.87 ± 6.67
		10%	33.21 ± 7.71	98.96 ± 3.50	130.77 ± 4.46
		20%	31.75 ± 7.08	99.26 ± 4.49	131.01 ± 3.91
		30%	33.15 ± 5.95	98.70 ± 2.66	129.82 ± 5.39
		Total	32.78 ± 7.22	98.92 ± 3.65	130.60 ± 5.03
	Total	BW	34.68 ± 7.43	94.90 ± 5.71	130.10 ± 5.87
		10%	35.67 ± 7.17	95.18 ± 5.45	129.69 ± 4.59
		20%	34.62 ± 7.37	94.86 ± 6.56	130.61 ± 4.64
		30%	35.44 ± 5.95	95.09 ± 4.90	129.21 ± 5.24
		Total	35.10 ± 6.87	95.00 ± 5.58	129.93 ± 5.03

Table 6: Peak plantarflexion and dorsiflexion values (mean degrees ± SD) on land

Condition	Sport	Load	Range	Plantarflexion	Dorsiflexion
Land	Gymnast	BW	55.81 ± 4.30	179.33 ± 3.80	123.50 ± 5.10
		10%	54.03 ± 5.46	177.63 ± 5.18	123.60 ± 7.89
		20%	54.91 ± 6.30	177.38 ± 4.49	122.46 ± 8.67
		30%	56.10 ± 3.65	179.78 ± 4.68	122.99 ± 7.84
		Total	55.25 ± 4.83	178.56 ± 4.44	123.13 ± 7.09
	Soccer	BW	32.18 ± 17.87	153. 45 ± 23.19	120.23 ± 5.09
		10%	32.24 ± 16.12	154.80 ± 22.51	122.56 ± 7.84
		20%	30.50 ± 14.43	153.07 ± 23.12	122.56 ± 10.63
		30%	31.36 ± 13.57	153.40 ± 22.04	122.03 ± 10.35
		Total	31.59 ± 15.07	153.67 ± 21.87	121.84 ± 8.48
	Total	BW	42.13 ± 18.12	164.35 ± 21.83	121.68 ± 5.22
		10%	41.21 ± 16.72	164.20 ± 20.72	122.98 ± 7.63
		20%	41.35 ± 16.80	163.87 ± 21.11	122.52 ± 9.53
		30%	42.36 ± 16.21	165.12 ± 21.17	122.42 ± 9.14
		Total	41.78 ± 16.64	164.39 ± 20.78	122.39 ± 7.88

Table 7: Peak plantarflexion and dorsiflexion values (mean degrees ± SD) in water

Condition	Sport	Load	Range	Plantarflexion	Dorsiflexion
Water	Gymnast	BW	51.48 ± 6.70	178.2 ± 6.67	126.71 ± 6.45
		10%	52.32 ± 4.62	176.61 ± 6.74	124.29 ± 7.85
		20%	51.92 ± 5.85	177.37 ± 8.27	125.45 ± 7.01
		30%	51.14 ± 11.63	178.44 ± 7.42	124.22 ± 6.75
		Total	51.70 ± 7.38	177.69 ± 6.99	125.23 ± 6.72
	Soccer	BW	32.04 ± 8.09	156.36 ± 14.08	122.07 ± 6.39
		10%	31.17 ± 9.13	155.38 ± 17.48	124.21 ± 9.99
		20%	30.15 ± 10.36	155.36 ± 18.62	125.20 ± 10.16
		30%	31.13 ± 11.45	156.20 ± 20.17	125.05 ± 9.94
		Total	31.15 ± 9.45	155.83 ± 16.97	124.13 ± 8.98
	Total	BW	40.23 ± 12.29	165.55 ± 15.81	124.13 ± 6.66
		10%	39.88 ± 13.04	164.12 ± 17.46	124.24 ± 8.90
		20%	39.83 ± 13.95	165.14 ± 18.39	125.31 ± 8.66
		30%	40.03 ± 15.16	166.08 ± 19.17	124.71 ± 8.53
		Total	39.99 ± 13.35	165.24 ± 17.37	124.60 ± 8.05

Table 8: Peak thigh angular velocites (mean °/s) on land

Condition	Sport	Load	Flexion	Extension
Land	Gymnast	BW	135.65 ± 16.08	236.02 ± 27.32
		10%	128.79 ± 19.87	225.32 ± 29.16
		20%	111.19 + 16.92	223.37 ± 27.87
		30%	121.96 ± 10.40	217.57 ± 25.05
		Total	124.25 ± 17.82	225.58 ± 26.82
	Soccer	BW	144.78 ± 24.21	168.88 ± 62.62
		10%	136.63 ± 24.21	177.88 ± 57.68
		20%	130.84 ± 16.58	165.37 ± 50.56
		30%	127.88 ± 20.38	171.32 ± 42.19
		Total	135.03 ± 21.61	170.81 ± 52.20
	Total	BW	140.72 ± 20.94	197.15 ± 60.24
		10%	133.40 ± 20.99	197.42 ± 52.62
		20%	122.11 ± 20.04	191.15 ± 50.52
		30%	125.2 ± 16.54	191.87 ± 41.95
		Total	130.33 ± 20.62	194.39 ± 50.84

Table 9: Peak thigh angular velocites (mean °/s) in water

Condition	Sport	Load	Flexion	Extension
Water	Gymnast	BW	110.33 ± 15.26	196.07 ± 24.05
		10%	99.89 ± 6.43	184.46 ± 19.69
		20%	104.42 ± 9.49	186.98 ± 23.08
		30%	100.63 ± 13.11	192.85 ± 25.99
		Total	103.95 ± 11.89	190.27 ± 22.71
	Soccer	BW	101.18 ± 18.66	161.56 ± 51.12
		10%	100.71 ± 19.43	151.03 ± 61.51
		20%	96.24 ± 19.09	154.65 ± 50.17
		30%	98.39 ± 20.87	155.07 ± 49.51
		Total	99.13 ± 18.87	155.72 ± 51.36
	Total	BW	105.25 ± 17.38	176.09 ± 44.53
		10%	100.37 ± 15.10	164.80 ± 50.61
		20%	99.88 ± 15.73	169.02 ± 42.72
		30%	99.39 ± 17.40	171.86 ± 44.15
		Total	101.23 ± 16.27	170.60 ± 44.73

Table 10: Peak shank angular velocities (mean °/s) on land

Condition	Sport	Load	Flexion	Extension
Land	Gymnast	BW	85.37 ± 13.34	257.67 ± 37.97
		10%	84.40 ± 15.91	245.65 ± 47.26
		20%	73.61 ± 12.75	260.64 ± 52.80
		30%	77.46 ± 12.99	256.10 ± 41.67
		Total	79.93 ± 13.84	255.32 ± 43.23
	Soccer	BW	97.20 ± 20.56	139.60 ± 66.58
		10%	89.69 ± 18.00	137.27 ± 52.51
		20%	84.93 ± 23.01	127.45 ± 47.38
		30%	80.70 ± 21.48	138.20 ± 56.34
		Total	88.09 ± 21.03	135.73 ± 54.51
	Total	BW	91.94 ± 18.26	189.31 ± 81.30
		10%	87.58 ± 16.81	181.90 ± 73.56
		20%	79.90 ± 19.51	186.65 ± 83.51
		30%	79.26 ± 17.79	190.60 ± 77.65
		Total	84.54 ± 18.59	187.22 ± 77.59

Table 11: Peak shank angular velocities (mean °/s) in water

Condition	Sport	Load	Flexion	Extension
Water	Gymnast	BW	76.26 ± 9.26	200.36 ± 35.89
		10%	70.92 ± 10.61	219.50 ± 57.46
		20%	73.61 ± 14.51	229.21 ± 33.14
		30%	70.68 ± 6.65	258.25 ± 81.88
		Total	73.00 ± 10.35	227.07 ± 56.97
	Soccer	BW	76.25 ± 18.11	113.20 ± 33.76
		10%	75.02 ± 15.61	99.11 ± 30.28
		20%	70.34 ± 12.74	110.53 ± 53.85
		30%	69.73 ± 16.56	120.45 ± 60.74
		Total	72.78 ± 15.52	110.88 ± 45.09
	Total	BW	76.25 ± 14.46	149.90 ± 55.57
		10%	73.38 ± 13.65	148.69 ± 74.05
		20%	71.80 ± 13.25	163.28 ± 75.30
		30%	70.15 ± 12.79	181.69 ± 98.38
		Total	72.87 ± 13.42	160.91 ± 76.63

Table 12: Peak foot angular velocities (mean °/s) on land

Condition	Sport	Load	Dorsiflexion	Plantarflexion
Land	Gymnast	BW	67.73 ± 23.03	257.67 ± 37.97
		10%	73.72 ± 25.83	245.65 ± 47.26
		20%	66.69 ± 22.11	260.64 ± 52.80
		30%	76.20 ± 24.46	256.10 ± 41.67
		Total	71.00 ± 22.97	255.32 ± 43.24
	Soccer	BW	31.71 ± 52.71	139.60 ± 66.58
		10%	17.28 ± 30.70	137.27 ± 52.51
		20%	9.32 ± 7.50	127.45 ± 47.38
		30%	17.31 ± 21.42	138.20 ± 56.34
		Total	19.29 ± 32.92	135.73 ± 54.51
	Total	BW	48.66 ± 44.32	189.31 ± 81.30
		10%	43.62 ± 40.08	181.90 ± 73.56
		20%	38.01 ± 33.65	186.65 ± 83.51
		30%	46.76 ± 37.66	190.60 ± 77.65
		Total	44.34 ± 38.47	187.22 ± 77.59

Table 13: Peak foot angular velocities (mean °/s) in water

Condition	Sport	Load	Dorsiflexion	Plantarflexion
Water	Gymnast	BW	84.49 ± 23.31	200.36 ± 35.89
		10%	76.87 ± 31.19	219.50 ± 57.46
		20%	87.63 ± 24.53	229.21 ± 33.14
		30%	85.71 ± 26.06	258.25 ± 81.88
		Total	83.89 ± 25.23	227.07 ± 56.97
	Soccer	BW	23.56 ± 20.86	113.20 ± 33.76
		10%	13.24 ± 5.44	99.11 ± 30.28
		20%	12.68 ± 8.98	110.53 ± 53.85
		30%	12.35 ± 10.40	120.45 ± 60.74
		Total	15.70 ± 13.44	110.88 ± 45.09
	Total	BW	52.23 ± 37.92	149.90 ± 55.57
		10%	42.93 ± 38.87	148.69 ± 74.05
		20%	50.16 ± 42.62	163.28 ± 75.30
		30%	49.03 ± 42.45	181.69 ± 98.38
		Total	48.73 ± 39.68	160.91 ± 76.63

Figure 1: Free body diagram displaying measured segment angles during countermovement jump for thigh, shank, and foot.

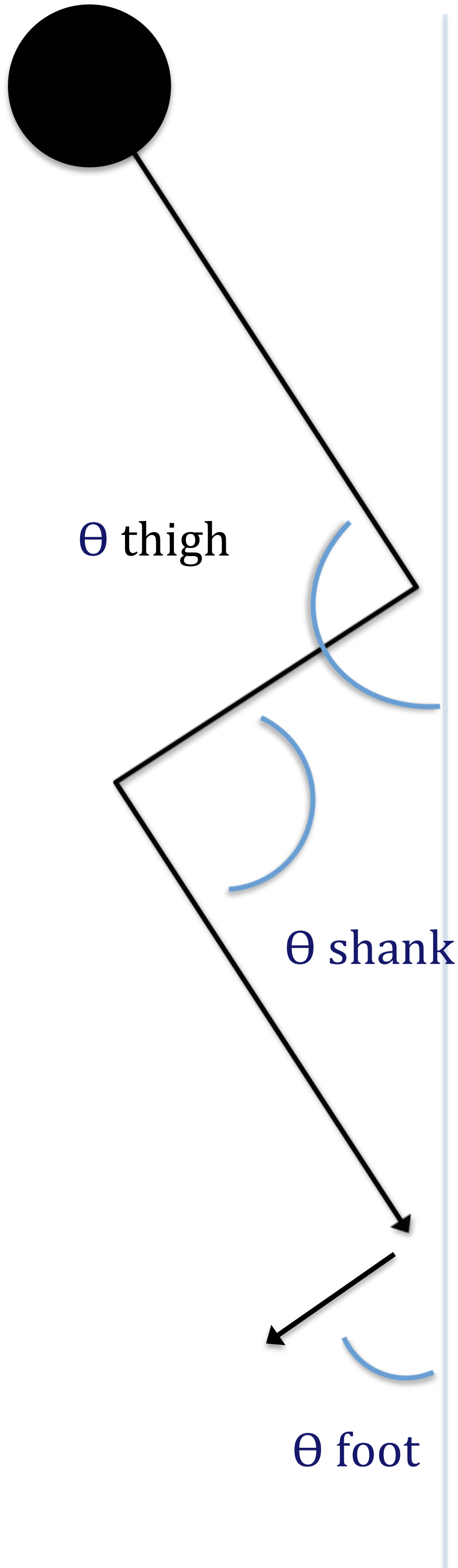

Figure 2: Digitization of anatomical landmarks (colored dots) using LoggerPro software of: 1) greater trochanter of femur (purple) 2) lateral epicondyle of femur (orange) 3) lateral malleolus of fibula (teal) 4) base of the 5th metatarsal (light blue), with green line representing linear distance reference (9.15 meters) and dark blue/red dots representing horizontal reference.

Figure 3: Graph displaying range of motion of thigh segment angle throughout countermovement jump (CMJ) where positive displacement is flexion and negative displacement is extension.

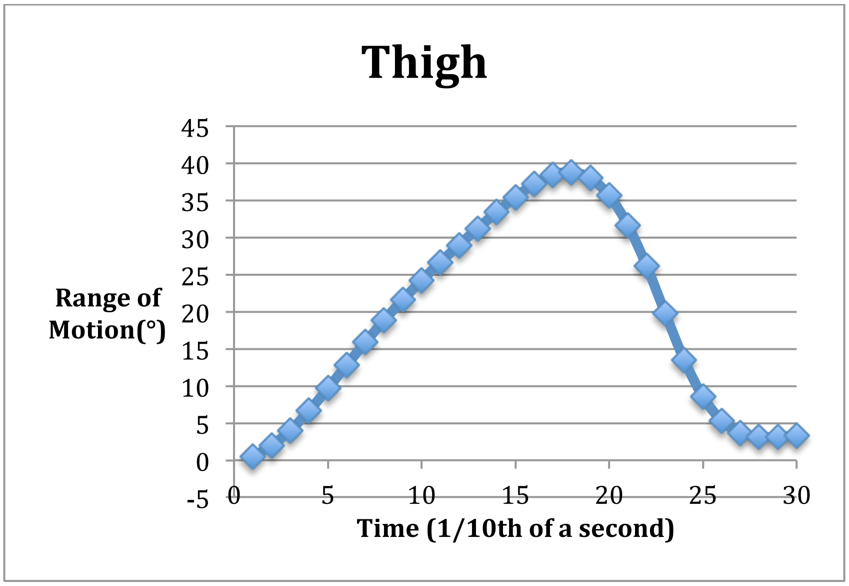

Figure 4: Graph displaying range of motion of shank segment angle throughout CMJ where positive displacement is extension and negative displacement is flexion.

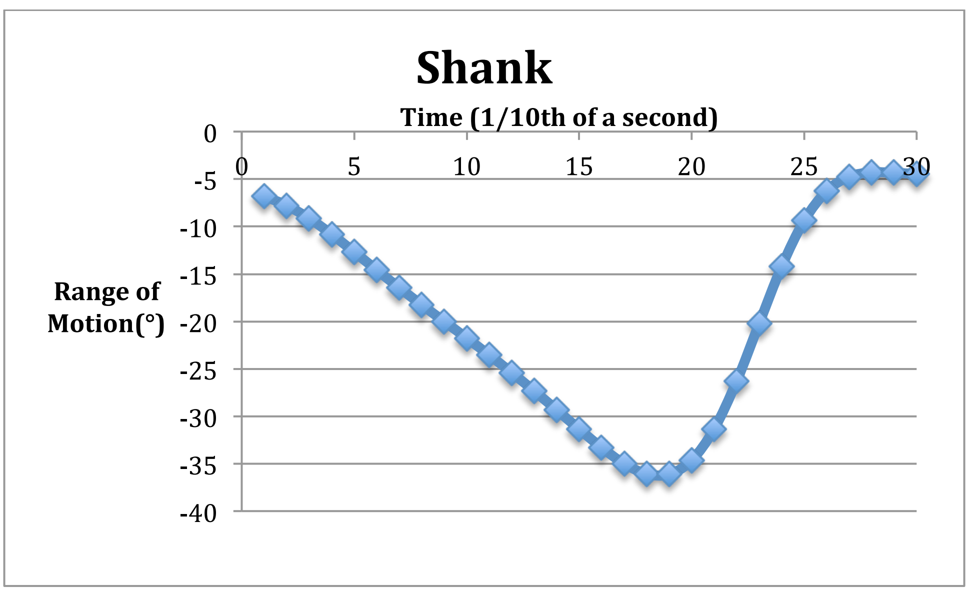

Figure 5: Graph displaying range of motion of foot segment angle throughout CMJ where positive displacement is plantarflexion and negative displacement is dorsiflexion.