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The Effects of 6 Weeks of Hip-Strengthening Exercises on Drop Jump Performance in Middle School Students

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The Effects of Six Weeks of Hip Muscle Exercises on Frontal Plane Knee Kinematics During a Drop Jump Test in Middle School-Aged Students

By

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Master's Thesis

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Abstract

The anterior cruciate ligament is the most frequently injured ligament in youth ages 8-14 (years) in the United States. This injury is often observed with abnormal valgus knee posture during dynamic landing tasks. Improvement of hip muscle function has positive associations with increasing lower extremity dynamic task competency. Much remains unknown with respect to the merit of integrating hip muscle-specific exercise programs in the aged 8-14 population for improving knee posture during jump landing. Therefore, the purpose of this investigation was to quantify the effects of 6-weeks of hip strengthening exercises on frontal plane knee position in the drop jump test with 7th-grade middle school students. The authors hypothesized that compared to the age-matched control group, the strength training group will show significant changes in frontal plane knee position, specifically a reduction in knee valgus, during drop landings. This intervention study included 57 youth (ages 12-13), who were randomly placed in an experimental or control group. First, to ascertain baseline knee position, all particpants were recorded performing the drop jump test facing a high speed camera. Then, the experimental group performed a series of dynamic warm-up and hip muscle-focused exercises for six weeks, while the control group completed a general warm-up. Post-intervention, pre-test procedures were replicated. A two-way mixed ANOVA was used to measure changes in frontal plane knee position from pre- to post-intervention. Results indicated that the exercise group achieved significantly greater post-intervention improvement in frontal plane knee position on the right knee ($p = 0.006$), with a mean difference of 7.52° change from valgus to varus posture during landing compared to the control. Further, the exercise group's left knee significantly differed in post-intervention frontal plane knee position compared to that of the control ($p = 0.011$), by an average of 6.87°. Overall, with the intervention program the exercise group landed in a less

valgus position from pre- to post-test. Six weeks of dynamic warm-up and hip muscle-focused exercises was effective in generating significant changes in frontal plane knee position during the landing phase of a drop jump in male and female 7th-grade middle school students.

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Chapter I: Introduction

Introduction

The encouragement of youth, particularly ages 8-14 years, to participate in some combination of structured physical practice and unregulated play is influenced, in part, by the relationship between sufficient physical activity and improved quality of life (Saunders et al., 2016). Further, the increased physical activity has strong correlations to enriching central and peripheral nervous system development during a crucial period of a person's development (Saunders et al., 2016). However, sport and leisure movement is not inherently risk-free, as virtually all forms of activity present unique challenges and necessitate varying degrees of competency to minimize the constituent liabilities (Junge, Runge, Juul-Kristensen, & Wedderkopp. 2016). A collaborative effort between healthcare professionals, physical education instructors, and fitness professionals to provide evidence-based, safe, and fun endeavors that satisfy physical activity guidelines appears to be a reasonable pursuit. To do so, evolving comprehension of the structures that produce motion and development of strategies to optimize function are worthwhile considerations.

The lower extremities are simultaneously a means of structural support, a form of transport, and a tool for producing a seemingly unlimited expression of motion (Avin, Bloomfield, Gross, & Warden, 2015; Pons, Moreno, Torricelli, & Taylor, 2013; Weppler & Magnusson, 2010). The gluteal muscle group (GMG), a collection of muscles, and the most prominent in the lower limbs, fulfill alternating roles as a joint stabilizer and producer of flexion, extension, abduction, internal rotation, and external rotation at the coxofemoral joint (Macadem & Feser, 2019; Neuman, 2010). The anterior cruciate ligament (ACL) is similar to the GMG with respect to commanding noteworthy distinction amongst peer tissues in the lower limb architecture, influenced in part by the pivotal responsibility of governing tibial anterior translation with respect to the femur in accordance with task demands and neuromotor capability (Duthon, Barea, Abrassart, Fasel, Fritschy, & Ménétrey, 2006; Markolf, Burchfield, Shapiro, Shepard, Finerman, & Slauterbeck, 1995). The ACL's status also presents an equivalent hereditary risk, as the injury rates surpass any other ligament in the United States (Kambhampati & Vaishya, 2019; Siegel, Vandenakker-Albanese, & Siegel, 2012). Most often, an ACL tear is resultant from an unforeseen internal rotation force linked with a valgus shift at the tibiofemoral joint that exceeds an individual's physiological/biomechanical preparedness (Choi, Yang, Jeong, & Lee, 2019; Powers, 2010; Siegel, Vandenakker-Albanese, & Siegel, 2012). This injury is often observed with abnormal valgus knee posture during dynamic loading such as jumping and sudden changes of direction. It has been posited that continued maintenance of the GMG can have a positive influence in reducing downstream workload of the patellofemoral and tibiofemoral joints during dynamic actions, thusly reducing the likelihood of ACL rupture through enhanced force resistance and structural integrity (Distefano & Blackburn, 2009; Flack, Nicholson, & Woodley, 2012; Macadem & Feser, 2019; Niinimäki, Härkönen, Nikander, Abe, Knüsel, & Sievänen, 2016; Rabelo & Lucareli, 2018). Further, several investigations have demonstrated improvements to the coxofemoral musculature producing favorable enhancements to dynamic movement by reducing valgus knee position during times of high impact, given the linked segment configuration of the lower extremities (Cooper, Scavo, & Strickland, 2016; Jabeen, Bashir, & Ehsan, 2016; Nakagawa, Moriya, Maciel, & Serrão, 2012; Souza, Draper, Fredericson, & Powers, 2010; Souza & Powers 2009; Boden, Sheehan, Torg, & Hewett, 2010).

The drop jump test (DJT) is regarded as a reliable and cost-effective method of ACL injury risk assessment in two-dimnesions and evaluator of hip muscle function improvement, as it poses similar demands seen in numerous physical tasks (Hewett et al., 2005; Pedley, Lloyd, Read, Moore, & Oliver, 2017). To the best of the authors' knowledge, investigating the effects of improving hip musculature strength or performance on mitigating dysfunctional frontal plane knee motion motion during drop jump landing using the DJT with middle school-aged youth has not been conducted, and given the accelerated rate of ACL injuries in the age group of 8-14 years (Ardern et al., 2018; Fabricant & Kocher, 2017), much remains to be explored with respect to potential strategies to mitigate the trend. Therefore, the purpose of this investigation was to examine the effects of a 6-week hip muscle strengthening program on maximum frontal plane position during the DJT. The authors hypothesized significant improvements in frontal plane knee position within and between groups after the exercise intervention, which would be indicated by reduced knee valgus.

Chapter II: Methodology

Subjects

A total of 76 (n = 37 males and n = 39 female) seventh-grade middle school students from two physical education (PE) instructor's classes volunteered to participate in the study. The participants were randomly assigned to either control or experimental group. No information was given to either group of participants regarding the variables of interest. Since the participants were minors, parents were given and asked to sign the parental consent form and each participant was asked to sign an assent form. The investigation was approved by Western Washington University's Institutional Review Board.

Procedures

A pre-test-posttest randomized group design was selected to for this investigation. By coin flip, one PE instructor's class was selected as the intervention, with the other becoming the control by proxy. A pre-intervention data collection was conducted to determine maximum frontal plane knee positionduring DJT for all participants. One male principal investigator (PI) performed all male participant bony landmark palpations and reflective marker (14 mm and 9.5 mm; two sizes were used to accommodate the volume of participants) placement for the left and right anterior superior iliac spine (ASIS), left and right tibial tuberosity, and the ventral midpoint between the lateral and medial malleoli, while one female rater repeated the procedure with all female participants. Pilot data were analyzed between the two investigators to assess marker placement repeatability and had ICC values of 1.00 and 0.99 for the left and right leg, respectively. Both raters followed a similar protocol to that of Souza and cohort (2010).

Data Collection

Once markers were placed, each participant was instructed to stand on a 30 cm box, 150 cm from the high-speed camera (Edgretronic, Sanstreak Corp, San Jose, California, USA) which was mounted on a tripod such that the camera lens was 60 cm from the ground, and connected to a laptop, using a similar set-up to Nor Adnan et al. (2018). To ensure only frontal plane motion was captured, the center of the camera lens was oriented orthogonally to the landing area of the box and leveled with an iPhone X (Apple, Cupertino, CA). Each participant was instructed to jump from the platform and land in a designated area 15 cm from the edge of the box. This was repeated for three jumps total per participant and recorded with a sampling of 250 Hz. The six-week exercise intervention for the experimental group was conducted on alternating two and three days per week intervals, per the academic calendar requirements of the middle school physical education schedule. Accordingly, the first week of the protocol included three exercise sessions, while the second week included two, which continued the same pattern for all six weeks, totaling 15 possible sessions for students to participate in. Attendance for all participants was tracked to ensure all participants participated in a minimum of 80% of the protocol, which all students whose post-DJT data were collected satisfied. During the intervention period, the control group was instructed to continue normal physical education activities in accordance with the instructor's curriculum without any exercise intervention at the start of the class. The exercise intervention included the following sequential dynamic warm-up and hip muscle-focused segments.

Dynamic Warm-Up

The dynamic warm-up portion consisted of the following exercises, which are supported by Samson, Button, Chaouachi, & Behm (2012). The first warm-up exercise was knee-to-chest pulls. The participants began in a standing position, with their feet shoulder width apart, and both arms resting at full extension. The participants elevated one leg by flexing at the hip, then grabbed the knee, and moderately pulled the knee/leg towards the chest with a 1-2 second hold at a self-selected height, subsequently returning the leg to the ground. The participants took 1-2 steps, then repeated the process with the other leg. This continued for a total of 10 meters (m). The second warm-up exercise was ankle grabs. The participants began in a standing position, with both feet shoulder width apart, and both arms resting at full extension. The participants then elevated the leg by flexing at the hip, then flexed at the knee, grabbed the ankle, and pulled the heel towards the posterior of the hip to move the hip into extension, keeping the knee in line with the hip, holding for 1-2 seconds to the point of feeling a stretch in the upper leg by the hand resisting the extension of the knee. The participants would let go of their foot and lower the leg back down to the ground. The participants took 1-2 steps and repeated the process with the other leg. This continued for a total of 10 m. The third warm-up exercise was hip cradles. The participants began in a standing position, with the feet shoulder width apart, and both arms resting at full extension. They elevated one leg with the knee flexed while rotating the foot towards the middle of the body. They grabbed the knee and foot simultaneously, then moderately flexed the knee/ankle/leg towards the chest with a 1-2 second hold, then returned the leg to the ground. The students took 1-2 steps, then repeated the process with the other leg. This continued for a total of 10 m. The fourth warm-up exercise was skipping. The participants skipped rhythmically at a self-selected pace for a total of 10 meters. The final warm-up exercise was the carioca. The participants began in a standing position, with the feet shoulder width apart, and both arms resting at full extension then made a 1/4 turn to the left. The participants moved laterally while using a cross-over step. One leg would push the body laterally, while the other leg crossed over, after which the leg that crossed over became the push-off leg upon landing, while the push-off leg became the cross-over leg, all while the student was continuously rotating at the hips. This was performed for a total of 10 m.

Hip Muscle-Focused Exercises

The hip muscle-focused portion consisted of the following exercises, which are supported by Reiman, Bolgla, and Loudon (2012): The first hip muscle activity in the sequence was clamshells. The participants began laying on the side of the body, with the legs together, and the knees and hip flexed at 90°. One arm was used to support the participant's heads while the other remained relaxed at the side. The participants abducted at the hip with the top leg, separating one knee from the other, with the top knee moving away from the bottom knee, but the feet remaining in contact with each other on the ground. The top knee would move until the participants could not go any further while maintaining their hip perpendicular to the ground. The top knee would then return to its starting position on top of the bottom knee via hip adduction for completion of one repetition. The participants did 10 repetitions on each leg. Each repetition was performed with instruction on the proper timing of each repetition. The second hip muscle exercise was the quadruped with contralateral arm/leg lift. The participants began on the hands and knees. The elbows were fully extended, the shoulder was flexed to 90°, and the hands were in line with the front of the shoulder. The knees were directly in line with the hips. At the command of the instructor, the students maximally extended their shoulder until parallel with the ground. Simultaneously, the students would extend the leg opposite of the elevated arm to an identical height. While doing this, the opposite arm and leg remained on the ground to maintain rigidity for balance. The students would keep the arm and leg elevated and extended for 2 seconds, then return the segments to the original position. This process was repeated with the opposite limbs and continued alternating until 10 repetitions were completed. The third hip muscle exercise was the plank. The participants began on their hands and knees, At the command of the instructor, the participants would extend the knees and support the body weight with the arms and legs for a total of 30 seconds. Participants unable to complete the full 30 seconds were allowed to terminate the exercise early and rest. This was completed one time. The fourth hip muscle exercise was the wall squat. The participants found a place near the gymnasium wall with adequate space between one another. The participants began in a standing position, with the feet shoulder width apart, both arms resting at full extension, and the back towards the wall. The participants then initiated the motion by flexing their trunk, followed by flexing the knees, until the dorsal region of the hips touched the wall. The participants paused for 1-2 seconds with the buttocks gently touching the wall, then slowly returned to the standing position for the completion of one repetition. The participants paused for 1-2 seconds with the hips gently touching the wall, then slowly returned to the standing position for the completion of one repetition. The participants performed 10 total repetitions. The final hip muscle exercise was the reverse lunge: The participants began in a standing position, with the feet shoulder width apart, both arms resting at full extension at their sides. The participants then stepped back 1-2 feet with one leg, keeping the other leg stationary, then lowered themselves towards the ground by flexing both knees, while keeping their torso upright. The participants were instructed to keep the knee of the front leg over the ankle and the knee of the rear leg in line with the hip. The participants lightly touched the rear knee to the ground, then elevated the body by extending both knees and returning the rear leg to the standing position for the completion of on repetition. This process was repeated with the other leg and continued until each leg completed 10 repetitions. The participants were continuously instructed with proper movement pacing.

After the six-week intervention, another DJT was conducted and video recorded, identical to the pre-intervention procedure. All videos were exported into Kinovea (www.kinovea.org; version 0.8.15) for analysis. Each video was cropped to isolate the portion of the DJT that began with initial contact of the participant's foot and ended at peak knee flexion. Initial contact was identified when both feet had begun to contact the floor, with no visible space between the toe-box of the shoes and the ground. Peak knee flexion was identified by determining when the torso and knees had completed flexion and began returning to extension. Once cropped, all six reflective markers at the left and right ASIS, left and right tibial tuberosity, and left and right ventral midpoint between the lateral and medial malleoli were digitized by the principal investigator. Frontal plane knee angle on each side was determined as the angle between two lines: 1) ASIS to tibial tuberosity, and 2) tibial tuberosity to ventral midpoint between the malleoli. The supplementary angle tool was used to indicate knee valgus as positive values. Each frame of the video was digitized, with the frontal plane knee angle being tracked simultaneously. The cropped video data were converted into line graphs of knee position vs time in Kinovea. All kinematic data for each participant were transferred to Microsoft Excel (Excel, Microsoft, Redmond, WA, US). The peak frontal plane knee valgus angle was identified in each DJT during the landing phase, then averaged for all 3 DJTs completed by each participant. This was performed for all participants in the intervention and control groups.

Statistical Analysis

A pre-test/post-test randomized group experimental protocol was employed for this investigation. All statistical analysis were performed in SPSS (version 27). A two-way mixed ANOVA was utilized to determine the effects of group (intervention vs. control) and time (pre-intervention vs. post-intervention) on maximal knee valgus of the right and left leg in the DJT. Alpha level was set at p <0.05. Effect size was calculated and interpreted as a partial eta-squared ($ŋp^2$) where $ŋp^2 > 0.15$ is large, $ŋp^2 > 0.06$ is medium, and $ŋp^2 > 0.01$ is small (Vincent, 1999).

Chapter III: Results

Results

Fifty-seven participants' data were included in the final analysis from the original 76 (Table 1). This decrease in sample size was a result of either a participant not completing a post-intervention data collection due to absence, an inability to digitize the participant's reflective marker as a result of poor lighting/video quality for some trials, or rotation at the participant's trunk and/or hips resulting in an inability to differentiate between knee valgus and knee flexion (i.e., out of plane movement). The assumption of sphericity was violated for both right and left leg peak knee frontal plane angles and the Greenhouse-Geiser value was used to assess statistical significance.

GROUP	n	AGE (years)	HEIGHT (cm)	MASS (kg)
Control Boys	**15**	12.9 ± 0.01	163.8 ± 0.53	58.6 ± 0.92
Control Girls	**16**	12.7 ± 0.03	158.8 ± 0.49	51.4 ± 0.79
Intervention Boys	**16**	12.8 ± 0.02	160.8 ± 0.54	50.2 ± 0.51
Intervention Girls	**10**	12.8 ± 0.42	158.7 ± 0.25	53.9 ± 0.72

Table 1. Antropometric averages for control and intervention groups ± SEM

Left Knee Joint Frontal Plane Kinematics

A significant interaction was observed between time and group (F [1, 56] = 9.814, p = 0.003, $ŋp^2$ = 0.151) in the left knee joint frontal plane motion (Figure 1). Simple effects analyses of time revealed no statistical significance in frontal plane kinematics in the left knee joint for the entire sample of participants in the pre-intervention DJT (p = 0.984). However, a significant difference was observed between groups during the post-intervention (p = 0.011) with the intervention group differing by an average of 6.87° in the varus direction compared to the controls. Simple effect analyses of group showed that the control group was not statistically significant between pre- and post-intervention ($p = 0.999$). Conversely, the intervention group showed a statistically significant difference between pre- and post-intervention ($p < 0.001$) with a mean difference of 6.92° in the varus direction.

Right Knee Joint Frontal Plane Kinematics

A significant interaction was seen between time and group (F [1, 55] = 6.666, $p = 0.013$, $\eta p^2 = 0.108$) in the left knee joint frontal plane motion (Figure 2). No significant difference was observed for the entire group of participants during the pre-intervention in frontal plane kinematics ($p = 0.358$). However, simple effects analyses of time revealed a statistical significance in frontal plane kinematics in the right knee joint between groups during the post-intervention ($p = 0.006$) with the intervention group differing by an average of 7.52° in the varus direction compared to the controls. Simple effect analyses of group showed that the control group was not statistically significant between pre- and post-intervention ($p = 0.510$). Though, the intervention group showed a statistically significant difference between pre- and post-intervention ($p < 0.001$) with a mean difference of 6.01° in the varus direction.

Inter-Limb Difference

A one-way ANOVA calculated the inter-limb differences for the entire population of participants during the pre-intervention DJT, with no significance observed (F [1, 56] = 0.001, $p = 0.971$, $\eta p^2 < 0.001$). An additional two-way mixed ANOVA was implemented to further quantify the post-intervention disparity between groups. No interaction between group and side was observed (F [1, 55] = 0.081, $p = 0.777$, $\eta p^2 = 0.001$), however, a significant main effect of group was identified (F [1, 55] = 9.396, p = 0.003, $\eta p^2 = 0.146$), with no significant differences between limbs within each group (p = 0.898).

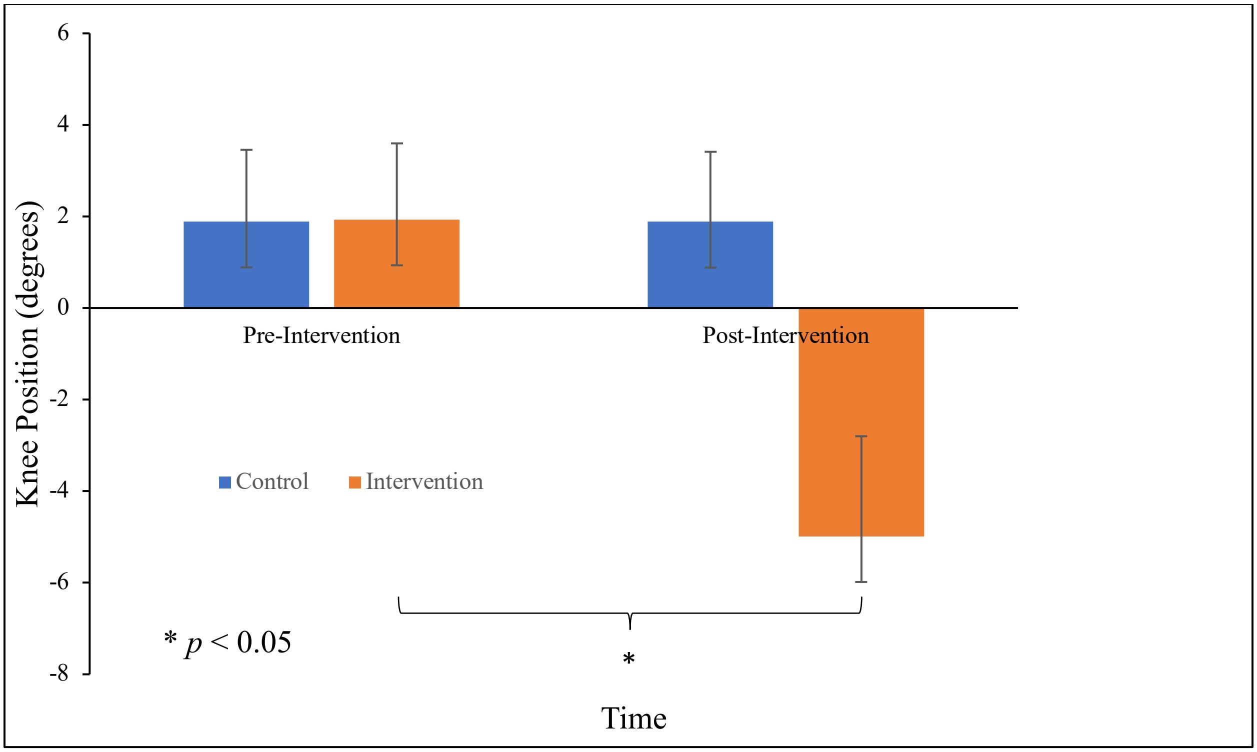

Figure 1. Left leg mean ± SEM frontal plane peak knee position during the drop jump before & after intervention for both groups. Positive values indicate knee valgus and negative values indicate knee varus.

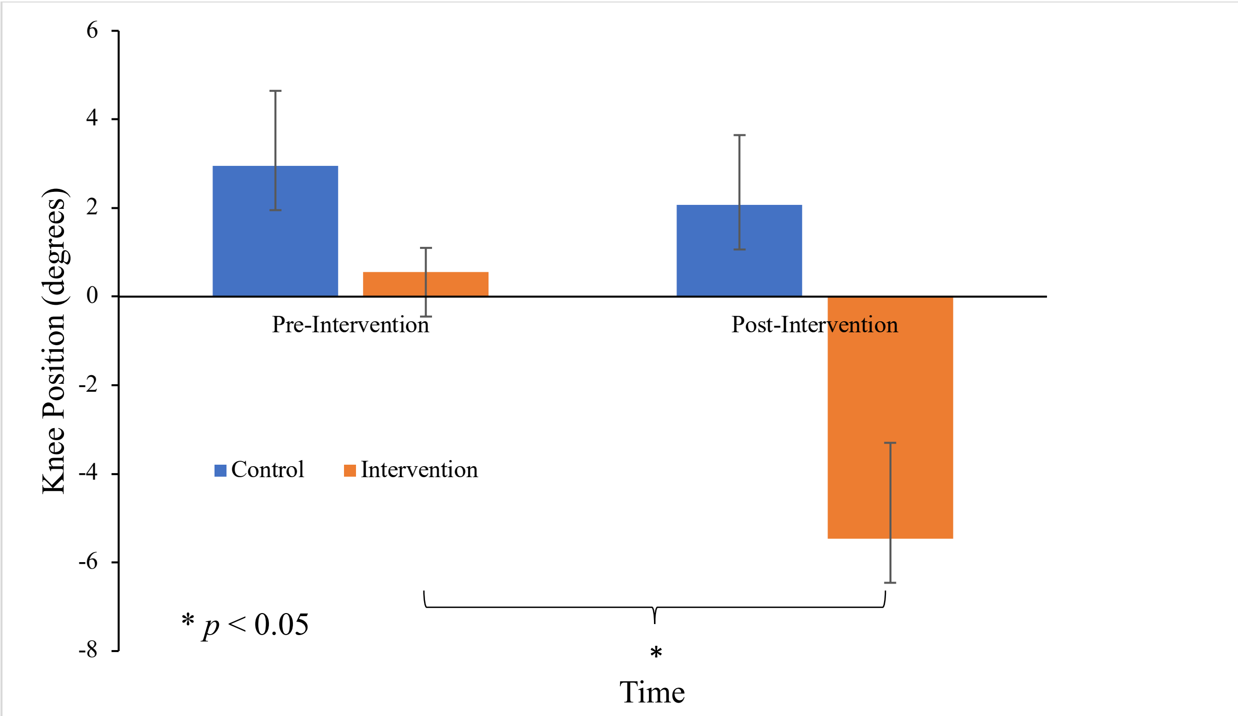

Figure 2. Right leg mean ± SEM frontal plane peak knee position during the drop jump before & after intervention for both groups. Positive values indicate knee valus and negative values indicate knee varus.

Chapter IV: Discussion

Discussion

The purpose of this investigation was to measure the efficacy of a six-week dynamic warm-up and hip muscle exercise program in promoting more effective landing mechanics during a DJT in seventh-grade middle school students. The key variable in evaluating the intervention's merit was observing improvements in knee position as determined by reductions in peak knee valgus during the landing phase of the DJT. The hypothesis that the exercise group would achieve significant changes in the post-intervention DJT knee position when compared to pre-intervention DJT against the results of the control group was supported.

The participants in this investigation did not receive any formal instruction on DJT execution, nor during the course of the intervention. As far as the authors are aware, the participants also had not ever received guidance on performing the DJT. Therefore, a learning effect on completion of the DJT can potentially be excluded as a confounding factor, particularly when considering that the control group did not achieve a significant reduction of knee valgus after the intervention.

The intervention group's right knee significantly differed from pre to post-intervention while the control group's right knee did not. On average, the intervention group demonstrated a 6.01° shift from valgus to varus knee joint frontal plane angle during the landing phase of the DJT, which differed from the control group by an average of 7.52°. A similar significant change was observed on the left knee of the exercise group, averaging a 6.92° shift from valgus to varus, with a mean difference of 6.87° compared to the control group, who did not demonstrate significant changes. No significant differences were observed between limbs for the entire group of participant's peak frontal plane knee position during the landing phase of the pre-intervention DJT. As such, the degree of change in knee position observed between groups can potentially be attributed to the intervention, given all participants essentially started with a relatively similar landing pattern in the frontal plane.

Work by Boden (2010) reported that a 2° of valgus shift at the tibiofemoral joint subsequently decreases ACL tolerance of compressive forces by the equivalent of one body mass, reduces lateral ligament rigidity, increases medial ligament stiffness, and promotes an anterior drift of the tibial plateau, which if combined with an internal rotation force could increase risk of an ACL tear. The observations by Boden (2010) support the focus of this investigation being reducing knee valgus during dynamic tasks. Though knee valgus is not the sole variable responsible for lower extremity injuires, the correlations with patellofemoral pain and ACL tears are not to be ignored (Boden, 2010; Ueno et al, 2020; Waiteman et al., 2018). Claiborne, Armstrong, Gandhi, and Pincivero (2006) revealed a significant relationship between hip muscle strength and frontal plane knee motion in a healthy adult population, where greater hip abduction was associated with reduced knee valgus. These associations potentially lend credence to the results of the current study, as the dynamic warm-up and hip muscle exercises selected might have influenced an increase in hip muscle strength. More recently, Malloy and cohort (2016) reported significant positive relationships between external rotation strength of the hip muscles and lateral excursion of the knee, meaning those possessing greater hip external rotation strength tended to markedly reduce knee valgus during a myriad of sport-specific landing activities. The dynamic warm-up and hip muscle exercises assigned in this intervention included a significant volume of motions that challenged abductors, external rotators, and stability of the hip. It is reasonable to suspect that repeated exposures to patterns that imposed demands on the aforementioned structures likely contributed to the average reduction in knee valgus. However, without objective measurements that verify an increase in strength this assessment requires further investigation. Araújo and cohort (2017) evaluated the efficacy of a hip and trunk muscle strengthening protocol on reducing knee valgus during a step-down activity in a population of women with a propensity for knee valgus. Compared to a control group of women with similar knee behavior, the exercise group achieved a pronounced reduction of lower extremity adduction. Key differences should be noted between the present study and that of Araújo and colleagues (2017). The current study included males and females 7th-grade middle school participants, while the population of Araújo and associates (2017) was that of adult females. Further, the present study only incorporated bodyweight exercises, counter to that of Araújo et al who utilized resistance training exercises with loads between 70 to 80% of the participant's one-rep maximum. Moreover, Araújo et al. evaluated knee position three-dimensionally via a step-down task while the current investigation implemented the more dynamic DJT through 2-D analysis. Collectively, the work of Araújo (2017) further connects the potential efficacy of exercises focused on the hip musculature on improving dynamic command of the lower extremities. The results of this study and combined observations of Boden (2010), Claiborne et al. (2006), Malloy et al. (2016), and Araújo et al. (2017) collectively suggest that exposures to patterns that challenge the hip in multiple planes, as well as induce mechanical stress through the three degrees of freedom, has potential to promote greater competency during landing tasks.

Limitations of this investigation include the activities of all participants not being tracked or regulated, which might have influenced the changes seen in the intervention group and the degree of difference observed between groups Additionally, muscle strength was not included as a variable of interest, which restricts the potential conclusions that could be drawn regarding the mechanisms that produced the observed changes in knee position in the exercise group.

Handheld dynamometer testing of hip muscle strength would be a strong candidate for future explorations of this topic. Analysis of ground reaction forces during the landing phase of the DJT via force plate is another potentially meaningful consideration, as more insight to the exercise group's capacity for force absorption could be illuminated, which could further yield intriguing observations regarding the degree of dynamic control improvement achievable in youth who participate in structured, hip muscle-focused exercise regimens. Finally, the inclusion of sagittal plane kinematics could yield greater insight into an individual's landing (i.e. hip or knee dominant) strategy, which might add more substance to analyzing an exercise programs' merit.

Conclusions

A six-week intervention of dynamic warm-up and hip muscle-focused exercises was effective in improving landing knee joint kinematics by reducing knee valgus in the DJT in a group of 7th-grade middle school student males and females when compared to a control group of the same age. The reductions in peak knee valgus position observed during DJT could be useful in the pursuit of mitigating lower-extremity injury risk, particularly anterior knee pain or more debilitating injuries like ACL tears, during dynamic tasks. Further, the improvements in knee postion within the exercise group were achieved in 15 sessions, averaging 8 minutes each, which might be useful for those working with middle school-aged youth looking to improve landing mechanics and are concerned with the amount of time needed. Continued exploration of this topic is warranted in the ongoing task of providing safe, effective exercises that reduce the probability of lower extremity injury risk and potentially increase dynamic task performance.

Chapter V

REVIEW OF PERTINENT LITERATURE

Background

The intention of this literature review is to explore the potential influences of the rising rate in anterior cruciate ligament (ACL) injuries in youth and support the implementation of a hip-strengthening exercise protocol in middle-school-aged children. Included in this review will be the following subtopics. A brief review of lower limb anatomy, including the primary joints and muscles will be discussed. The ACL will be described with connections made to its contributions to lower limb kinematics during running and landing from a jump and what risk factors exist that pose a threat to the ACL's integrity. The role of the gluteal muscle group will be included in the discourse to describe how said ACL risk factors can be managed, with a consensus amongst healthcare professionals regarding the most appropriate exercises for targeting the gluteal muscles being provided. Analysis of previous research that has utilized the drop jump test (DJT) as a means of evaluating lower limb kinematics in the pursuit of estimating ACL injury risk and evaluating the efficacy of incorporating gluteal muscle exercises will be included to justify its utility for implementation. The purpose of this investigation is to incorporate the knowledge into exploring the effects of integrating six weeks of hip-strengthening exercises with middle-school-aged children, with the DJT serving as the metric of the program's efficacy.

The encouragement of youth to participate in sport and play by healthcare professionals is influenced by the relationship between sufficient physical activity and improved quality of life (Saunders et al., 2016). Indeed, increasing rates of physical inactivity and the global burden of rising related health care costs (Ding, Kolbe-Alexander, Nguyen, Katzmarzyk, Pratt, & Lawson,

2017) are notable components to this strong advocacy of sport and play by healthcare professionals (Júdice, Silva, Berria, Petroski, Ekelund, & Sardinha, 2017). However, sport and play are not inherently without risk, like all forms of activity present unique physical challenges and necessitate varying degrees of competency to minimize the constituent liabilities (Saunders et al., 2016; Junge, Runge, Juul-Kristensen, & Wedderkopp, 2016; Kellis, Mademli, Patikas, & Kofotolis, 2014). A growing concern amongst healthcare professionals is an observed increase in the rate of anterior cruciate ligament (ACL) injuries amongst youth (Ardern et al., 2017; Fabricant & Kocher, 2017; Junge, Runge, Juul-Kristensen, & Wedderkopp, 2016; Kambhampati & Vaishy, 2019) with the aforementioned concomitant decline in physical activity (Ding, Kolbe-Alexander, Nguyen, Katzmarzyk, Pratt, & Lawson, 2017; 2, Júdice, Silva, Berria, Petroski, Ekelund, & Sardinha, 2017; 25). As such, interventions should be explored that aid in the mitigation of the current ACL injury rate trend, increase physical competency, and improve overall well-being (Ainswortth et al., 2019; Katzmarzyk et al, 2016). To begin with, a thorough understanding of lower limb anatomy is essential.

Lower Limb Anatomy & Biomechanics

The lower extremities of the human body consist of a collaborative relationship between a framework of bones, muscles, fascia, tendons, and ligaments that function to produce locomotion (Pons, Moreno, Torricelli, & Taylor, 2013). Via neural input, ligaments linking one bone to another, and tendons connecting muscle to bone to impart force, a myriad of movements can be produced (Avin, Bloomfield, Gross, & Warden, 2015; Weppler & Magnusson, 2010). Lower extremity prime movers in many activities include dorsal muscles such as the gluteus maximus, biceps femoris, and gastrocnemius (Ward, Eng, Smallwood, & Lieber, 2009). Prevalent ventral prime mover muscles include the rectus femoris, vastus lateralis, and the tibialis anterior (Ward, Eng, Smallwood, & Lieber, 2009). Primary joints of the lower limbs that the aforementioned muscles act upon including the coxofemoral, patellofemoral, tibiofemoral, and tibiotalar (Leardini, Belvedere, Nardini, Sancisi, Conconi, & Parenti-Castelli, 2017). Through the action of biarticular muscles, multiple joints can operate simultaneously, making cyclic movements like running and jumping, as well as functional daily tasks possible (Raasch & Zajac, 1999). As running and jumping are omnipresent in many sports and activities (Haible et al., 2019) further knowledge of the muscles that produce these motions, specifically those of the gluteal group, is pertinent to the central theme of this literature review. By establishing the cruciality of a muscle's role in commonly practiced movements, will aid in the understanding of why the development of the muscles will also support the reduction in the likelihood of an injury incident. To do so, the next section will focus on the structure and function of the ACL, the role of the gluteal muscles during running and jumping, and how that role relates to the causal mechanisms of the ACL injury.

ACL Injuries, The Gluteal Muscles, & The Value of Strength

The ACL is considered to be atop the hierarchy of knee ligaments (Markolf, Burchfield, Shapiro, Shepard, Finerman, & Slauterbeck, 1995). During running, jumping, and other functional daily tasks with repetitive knee flexion and extension, the ACL serves as a governor of tibial translation anteriorly, essentially ensuring the tibia moves within a certain range with respect to the femur in accordance with an individual's biomechanical competency (Duthon, Barea, Abrassart, Fasel, Fritschy, & Ménétrey, 2006). The ACL is the most frequently injured ligament in the United States (Kambhampati & Vaishya, 2019; Siegel, Vandenakker-Albanese, & Siegel, 2012). ACL injuries are a convergence of multiple biomechanical, neuromotor, physiological, and environmental factors that load the ligament beyond its capacity (Choi, Yang, Jeong, & Lee, 2019; Siegel, Vandenakker-Albanese, & Siegel, 2012; Powers, 2010). More specifically, when the patellofemoral joint experiences a sudden valgus shift (a change in joint position towards the midline of the body), with a simultaneous internal rotation force at the tibiofemoral joint, in such a way that the structure is not prepared for and/or at a degree of force that is beyond an individuals' limits, a rupture/tear is likely imminent (Choi, Yang, Jeong, & Lee, 2019; Siegel, Vandenakker-Albanese, & Siegel, 2012; Powers, 2010). This review will focus on potentially influential biomechanical factors, including the function of the gluteal muscle group given the established significant responsibility of the said group in the generation of running and jumping patterns and the accomplishment of functional daily tasks Distefano, Blackburn, Marshall, & Padua, 2009; Macadem & Feser, 2019; Niinimäki, Härkönen, Nikander, Abe, Knüsel, & Sievänen, 2016; Souza & Powers, 2009).

The hip muscles, which include the gluteus maximus, minimus, and medius, impart force on the coxofemoral joint to produce flexion, extension, adduction, abduction, internal rotation, and external rotation, which are generated concomitantly with the motions of the other primary lower extremity joints to facilitate motor patterns (Macadem & Feser, 2019; Neuman, 2010). It has been posited that a weakness in the gluteal group has a systemic influence on the knee joint during functional movements (Distefano, Blackburn, Marshall, & Padua, 2009; Rabelo & Lucareli, 2018). This observation is supported by the function of the gluteal muscle group as a prime mover and coxofemoral joint stabilizer during functional motions (Distefano, Blackburn, Marshall, & Padua, 2009; Flack, Nicholson, & Woodley, 2012; Macadem & Feser, 2019; Niinimäki, Härkönen, Nikander, Abe, Knüsel, & Sievänen, 2016; Neuman, 2010). To further explore this observation, the concept of motor pattern compensation is relevant, as it pertains to making the connection between the gluteal muscles and ACL injury. Generally, a learned pattern has a defined sequence of muscle activation and structure coordination to accomplish a task (Hanawa et al., 2017). As such, it is not unreasonable to infer that a perturbation to one component of the lower extremities would potentially result in a change in the execution of a pattern, with potential ramifications to other structures, given the interconnected relationship of structures during movements (Cappellini, Ivanenko, Poppele, & Lacquaniti, 2006; Hanawa et al., 2017; Neuman, 2010; Rosen, Ko, Simpson, Kim, & Brown, 2015; Siegel, Kepple, & Stanhope, 2007). This concept has been explored in different structures across many investigations.

Siegel, Kepple, and Stanhope (2007) investigated the disparity in gait strategy between one healthy female subject and three with hip idiopathic inflammatory myopathies (IIM), which are marked by significant inflammation and severely restrict the force capacity of a muscle group. The intention of Siegel et al. (2007) was to further illuminate the impact of muscular weakness on gait execution. Siegel and cohort (2007) reported subjects with IIM tended to walk slower. Furthermore, Siegel et al. (2007) observed changes in joint position, including increasing knee flexion to compensate for the repressed hip extension that results from weak hip flexors. Siegel et al. (2007) suggest the combination of muscle weakness and increased knee flexion could contribute to future structural impairment. The work of Siegel and colleagues (2007) contributes to the annotation of the systemic influence one muscle group can have on neighboring structures. It is worth noting that the small sample size of this investigation restricts the application across broader populations.

Thompson and associates (2013) explored the muscular force changes in walking gait after mimicking three variations of quadriceps weakness: atrophy, maximum activation reduction, and a combination of the two, in a simulated muscle model. By decreasing the capacity of one muscle group, the gluteus maximus and soleus compensated by means of increasing both force production and forward progression generation. The observations by Thompson et al. (2013) advocate for the development of quadriceps strength and suggest weakness to be a potential indication of gait performance reduction, as a loss in forward progression reduces the efficiency of the pattern, which is not optimal from an energetics standpoint. The work of Thompson et al. (2013) supports the concept of the potential downstream effects on structures as a result of sub-optimal muscular performance.

Feger and colleagues (2015) analyzed the muscle activation patterns of the lower limbs in n = 15 healthy subjects and n = 15 with chronic ankle instability (CAI), which is partially characterized by weakness in the ankle structure, during a controlled speed-controlled treadmill walking condition. The muscles measured in this study included the anterior tibialis, peroneus longus, lateral gastrocnemius, rectus femoris, biceps femoris, and gluteus medius via surface electromyography (EMG). The results of Feger and cohort (2015) revealed the peroneus longus of CAI subjects to remain active for a greater duration than healthy subjects. Additionally, all muscles measured activated earlier in the gait cycle for CAI subjects than healthy subjects. These strategies, while successful in providing the CAI subjects a means to remain mobile and complete daily functional tasks, provoked concerns with Feger et al. (2015), in that longer activation times could reduce muscle efficiency and increase injury risk as a result of overworked tissues. The work of Feger et al. (2015) adds evidence to the suggestion that manipulations to the muscular activation patterns of a movement can contribute to a change in the execution of the motion, which may result in sub-optimal outcomes. Additionally, Feger and colleagues' (2015) work moderately highlights the cruciality of glute strength, as the study demonstrates the glute muscles' ability to provide additional functional support when another structure's performance is sub-optimal.

Nelson-Wong, Gregory, Winter, and Callaghan (2008) collaborated on intriguing work involving the gluteal muscle group and the associated recruitment patterns in individuals with and without lower back pain (LBP) to identify disparities in gluteal muscle group function between populations. The hypothesis of Nelson-Wong and cohort (2008) was that participants with LBP would have significantly different gluteal muscle activation patterns than those without LBP. Answering this hypothesis would serve as a means of developing preventative measures against LBP through the identification of recruitment patterns seen in those who had LBP. A population of n = 23 (11 females, 12 males) with no LBP incidents within the last 12 months were recruited for this investigation. To identify LBP muscle activation patterns, a two-hour office-related task simulation was conducted, where reports of the neck, shoulder, upper and lower back pain were ascertained at 15-minute intervals by an independent researcher. Concomitantly, surface EMG data were recorded by the authors from the lumbar erector spinae, thoracic erector spinae, rectus abdominus, external oblique, and gluteus medius. Using established numerical indications from previous research, Nelson-Wong and cohort (2008) were able to identify when agonist-antagonist muscles (left and right gluteus medius and lumbar erector spinae/external oblique) were being co-activated, a strong indication of LBP. As a result, Nelson-Wong and associates (2008) were able to predict the presence of LBP in 17/23 participants upon comparison with the pain data from the independent researcher in the post-task analysis. Additionally, Nelson-Wong et al. (2008) observed increased muscle activation variability in the non-LBP population, wherein the muscles of interest were firing at a greater frequency. The work of Nelson-Wong et al. (2008) demonstrates the potential ramifications of motor patterns that are not conducive to the task with the conclusion that muscle agonist-antagonist co-activation is not an effective strategy when standing for extended durations.

Nelson-Wong et al.'s (2008) observations are also relevant to the suggestion that injury risk can be potentially linked to certain muscle activation patterns, which is a worthy consideration in this literature review.

Souza and Powers (2009) investigated the disparity between coxofemoral muscle strength, muscle activation, and kinematics in a population (n = 41) of healthy females (n = 20) and those with patellofemoral pain (PFP; n = 21). Souza and Powers (2009) had all subjects complete a session of hip muscle strength testing using a dynamometer machine. Separate from the strength test, three physical tasks were completed. Task one was running at 180 meters/min for 15 meters, with contact on force plates occurring within the distance. Task two was a drop jump from a 35 cm platform to force plates. Task three was a step-down from a height equal to 10% of the participant's height, at a pace determined by a metronome, where one leg remained on the box while the other touched the floor with the heel. During these physical tasks, kinematic and EMG data were recorded. The muscles of interest in this study were the gluteus medius and maximus. The greatest divergence between groups was observed in the PFP group's larger peak hip internal rotation and reduced gluteal muscle group strength. Additionally, the running task is where PFP females exhibited the greatest difference in peak hip internal rotation compared to healthy females. Souza and Powers (2009) suggest that the observed modulation to coxofemoral kinematics may be a result of decreased gluteal muscle performance, but the design of the study does not allow for a direct connection. Nevertheless, Souza and Powers (2009) results do contribute to the estimation that a reduction in performance in one structure can plausibly influence the performance in others.

Souza, Draper, Fredericson, and Powers (2010) further explored the biomechanics of subjects with PFP compared to healthy controls in a study design that implemented Magnetic Resonance Imaging. Souza and colleagues (2010) aimed to identify differences between populations in femur rotation, patellar movement, and the potential influence of both on the kinematics of the patellofemoral joint. In a sample size of 30 subjects, 15 healthy and 15 with PFP, each participant performed a barefoot, unilateral squat to 50 degrees of knee flexion, with a pause at four distinct positions (45, 30, 15, and 0 degrees). Concurrently, MRI captured two images at each of the 4 distinct squat locations. This procedure was repeated after a 5-minute rest period. Souza et al. (2010) reported significant differences in PFP participants concerning patellar dislocation, patellar tilt, and internal rotation of the femur, all of which were predicted in the hypothesis. The greatest disparity in patellar motion between groups was seen at 0 degrees of knee flexion, the end range of the squat's concentric phase, with the PFP group producing the largest degree of lateral patellar dislocation. Souza and cohort (2010) suggest the prime influencer of the observed patellar motion disparity in PFP participants to be the excessive internal rotation of the femur, as both structures motions paralleled one another with respect to the degree and rate of change. Additionally, Souza and associates (2010) propose the detected motion of the femur in PFP females could impart considerable stress to the patellofemoral joint that might result in future complications. The relationship of femoral rotation to patellofemoral joint contact area, wherein an increase in the former results in a decrease in the latter, has been associated with marked rises in patellofemoral joint trauma (Jabeen, Bashir, & Ehsan, 2016; Powers, 2010; Rabelo & Lucareli, 2018; Souza, Draper, Fredericson, & Powers, 2010). The work by Souza and colleagues (2010) lends to the supposition that the execution of motor patterns can be significantly influenced by manipulations to the structure performing the task.

Souza et al. (2010) data also provide some credence to the notion that excessive femoral internal rotation could be a risk factor for future patellofemoral injuries, and training the muscles that control that motion, like the gluteal group, is one plausible solution.

Nakagawa, Moriya, Maciel, and SerrãO (2012), similar to Souza et al. (2009), sought to explore the intersex differences in glute muscle activation and kinematics of the knee, hip, pelvis, and trunk amongst a population of participants who did or did not possess PFP. A total of n = 80 male and female subjects were divided into four, age-matched groups: females with PFP, female controls, males with PFP, and male controls. Glute muscle strength was evaluated utilizing maximal voluntary contraction during both hip abduction and extension using a hand-held dynamometer. These data were used to normalize against the EMG data collected during a single-leg squat test where knee, hip, pelvis, and trunk kinematics were also measured. Significant observations include exaggerated ipsilateral trunk lean, increased contralateral hip drop, and augmented hip adduction and knee abduction in subjects with PFP compared to healthy controls. Furthermore, in the lowering phase of the single-leg squat, PFP participants exhibited weakened external rotation and abduction at the hip compared to the healthy controls. These findings, along with greater hip internal rotation and reduced gluteus medius activity in the unilateral squat, were more prevalent in PFP women than PFP men. Intriguingly, during the unilateral squat, women tended to recruit the gluteal muscles at a larger percent of max effort relative to the recorded MVIC than male participants. The results of Nakagawa and cohort (33) suggest that those with PFP exhibit significant motor disparity when executing a single-leg squat, including impaired hip muscle activity and exaggerated shifting of trunk position, with a greater degree of difference in women compared to men. Nakagawa et al.'s (2012) work add support to the speculation that manipulation to one component of the human musculoskeletal system can influence neighboring structures. Additionally, the work of Nakagawa et al. (2012), while associative and not causal, suggests PFP be a potential outcome of weakened hip muscles and altered knee and trunk kinematics, which lends to the conjecture of the influence certain motor patterns can have on the health of structures if executed with sub-optimal muscle strength.

Cooper, Scavo, Strickland, Tipayamongkol, Nicholson, Bewyer, & Sluka (2016) conducted a sizeable investigation into the connection between gluteal muscle weakness and LBP. In a population of n = 225, 150 participants with LBP symptoms for longer than three months were compared to 75 non-LBP controls. Manual muscle testing, similar to that of Jabeen, Bashir, and Ehsan (21), for the gluteus maximus, gluteus medius, and tensor fascia latae was implemented to evaluate muscle strength. Observations for signs of Trendelenburg gait were conducted to establish the functional status of each participant. Palpations to the muscle belly of the gluteus medius, gluteus maximus, paraspinals of the lumbar, piriformis, and greater trochanter were conducted to locate tenderness. Analysis of Cooper et al.'s (2016) results reveal the LBP population to possess significantly weaker gluteal muscles (predominantly the gluteus medius), stronger indications of Trendelenburg gait, and increased muscle belly tenderness in all muscles of interest. Futhermore, Cooper et al. (2016) mention gluteus medius weakness to be the most reliable trait in the prediction of LBP. Cooper et al.'s (2016) work annexes more evidence to the notion of muscular performance reductions and structure modulations contributing to potentially negative outcomes, as well as illustrate the value of the GMG for reducing the workload of surrounding structures.

The discussed literature thus far aids in the illustration of the interconnected relationship of the human musculoskeletal system. Indeed, it is reasonable to suggest that each component relies on the other to accomplish physical tasks, and any reduction/modulation to one bears plausible, sometimes negative, consequences on one or several structures. In the pursuit of reducing the potential of disagreeable physical outcomes, muscular strength is an invaluable trait (Kraschnewski, Sciamanna, & Poger, 2016; Timpka, Petersson, Zhou, & Englund, 2014; Artero et al., 2011).

Muscle Strength & Injury Risk Management

Improving muscular performance is regarded to be a key constituent in the pursuit of adequate well-being, with strong evidence of improving task completion (Artero et al., 2011; Kellis, Mademli, Patikas, & Kofotolis, 2014; Kraschnewski, Sciamanna, & Poger, 2016; Øiestad, Juhl, Eitzen, & Thorlund, 2015; Timpka, Petersson, Zhou, & Englund, 2014). Jabeen, Bashir, and Ehsan (2016) completed similar work to that of Souza et al. (2009) and Nakagawa et al. (2012) in an exploration of the significance of gluteal muscle strength, flexibility of the hip musculature, and PFP in 40 female participants. Jabeen, Bashir, and Ehsan (2016) differed from previous investigations in that this study only analyzed subjects with PFP and used a novel approach of cross comparing the quantitative measures of gluteal muscle strength, flexibility of the hip musculature, and PFP for analysis. The flexibility testing methodologies included the Thomas Test for the rectus femoris, Ober's Test for the iliotibial band, and the passive straight-leg raise for the hamstrings. Gluteal muscle strength was evaluated using the manual muscle method, which is scored on a 1-5 scale. Pain was scored employing the Visual Analog Scale of 1-10. The functional status of the patellofemoral joint was established using the Anterior Knee Pain Questionnaire. Upon collection of each test's score, the data were collated and included in an equation to measure influence on PFP. The results of Jabeen and cohort (2016) revealed hip muscle strength to be the strongest indication of functional status in the study's participants, while flexibility was the weakest barometer of functional status. The work of Jabeen et al. (2016) reinforces the advocacy for increasing muscle strength as a means of supporting the accomplishment of functional daily tasks.

Araújo, Souza, Carvalhais, Cruz, and Fonseca (2017) evaluated the effectiveness of improving the strength in the trunk and coxofemoral musculature on lower extremity kinematics in a non-randomized control population of n = 36 women. In the preliminary kinematic evaluation, Araújo and cohort (2017) conducted a step-down task from an 18 cm box that was pace-controlled by metronome to last 3 seconds from start to finish. Further initial analysis by Araújo et al. (2017) included Biodex-measured passive hip torque during internal and external rotation, and work done by the hip lateral rotator muscles during eccentric and concentric actions while using the Biodex. Following the preliminary measurements, the participants were divided into an exercise group and control group. The exercise group completed five exercises consisting of three sets of eight repetitions, with one-minute rest in between sets, three times per week for eight weeks. Upon completion of the exercise intervention, each group completed the same testing modalities conducted in the preliminary evaluation. Results of the post-intervention analysis revealed the exercise group to increase the work capacity of the hip lateral rotators during eccentric and concentric activity on the Biodex while decreasing peak adduction at the knee during the step-down test. Additionally, Araújo et al. (2017) observed significant modulations to the coxofemoral joint resting position of the exercise group, noting a displacement toward external rotation. Araújo and colleagues (2017) conclude that high loading exercises for the hip and trunk musculature should be considered in the pursuit of improving lower-limb kinematics during dynamic activities, which is in line with the premise of this literature review.

Added, de Freitas, Kasawara, Martin, & Fukuda (2018) addressed the merit of improving strength in the gluteus maximus to subdue malfunction of the sacroiliac (SI) joint. A preliminary evaluation of n = 8 male (n = 4) and female (n = 4) subjects included gluteus maximus peak strength via handheld dynamometer, SI joint pain valuation via the Visual Analog Scale, usage of the Oswestry Disability Index, which is a participant-described grade of physical function, and baseline range-of-motion assessments of the hip and trunk. SI joint dysfunction was established through completion of four SI joint clinical tests, with a score of 3/4 positive tests producing a confirmed SI joint dysfunction diagnosis. The exercise intervention portion of the investigation consisted of two 30-miniute sessions per week for a total of five weeks. The first five sessions consisted of bodyweight exercises that emphasized hip extension. The next five sessions incorporated increased hip extension resistance via the deadlift exercise, and also included movements that focused on external rotation. In the post-intervention analysis, Added et al. (2018) reported all participants significantly increased gluteus maximus muscle strength while markedly reducing SI joint pain. Moreover, all subjects disclosed noteworthy elevations in physical function. While the work of Added et al. (2018) was completed with a restricted population, the significant results do speak to the role of hip muscle strength in the management of pain and potential to improve physical function.

The works in this section support the efficacy of increasing muscular performance from load-bearing activities in motions that mimic sport and activities of daily living on reducing injury risk. Increasing gluteal muscle group performance in isolation has yet to show a direct, causal relationship with reducing ACL injury potential. Nevertheless, the discussed literature in this review does provide sufficient support that there are substantial relationships between structures that, when disrupted, produce outcomes that can be unfavorable. Additionally, increasing muscle performance is a meaningful pursuit to manage injury risk and improve quality of life. Therefore, it is plausible to suggest that the fusing of the body of evidence makes a reasonable case for the focusing of improving hip muscle function in the pursuit of decreasing ACL injury risk. Another question that arises from this discussion is what reliable methods exist to identify ACL injury risk. The drop-jump test (DJT) is one such means of analysis that can serve that purpose.

The Drop Jump Test

The DJT is derived from plyometrics exercise training, the creation of which is accredited to Verkhoshanski (1973) who developed the inaugural iteration of the methodology to increase power, running speed, and other desirable physical performance traits in athletes. It was Wilt (1975), however, who conceived the word “plyometrics”, the etymology of which has Greek roots. Hewett et al. (2005) are credited with the commencement of using the drop jump as a means of screening individuals for motor patterns associated with knee injuries, as the demands of landing from a jump mirror those of typical physical activities and sport. The traditional structure of the DJT is as follows. An individual is asked to wear athletic clothing and be fitted with reflective markers that are placed on bony landmarks of the lower extremity by a trained professional to track motion. Once completed, the participant performs a jump from a platform of varying heights (sometimes determined by a person’s anthropometrics) and lands according to the individual’s preference, sometimes to a force plate, depending on the intention of the study. Since the foundational work of Hewett and associates (2005), numerous investigations have been organized in the pursuit of determining the utility of various motion analysis methodologies to identify knee injury risk factors.

Usefulness of a test begins, in part, with measuring the reliability and validity of the examination against a gold standard. In motion analysis, three-dimensional (3D) evaluation is regarded as the most accurate and precise method (39). However, the high cost and increased level of competency required to operate creates a barrier of entry that not all can overcome (Ortiz, Rosario-Canales, Rodríguez, Seda, Figueroa, & Venegas-Ríos, 2016; Paul, Lester, Foreman, & Dibble, 2016). Two-dimensional (2D) analysis offers an alternative to three-dimensional that is cost-effective and easier to operate (32). Ekegren and associates (2009) sought to address the reliability and validity of 2D motion analysis in an investigation that collaborated with three, well-trained professional physiotherapists (PT). A group of N = 40 soccer players performed the DJT while being filmed by 2D and 3D cameras, simultaneously. The PTs then performed two sessions of analysis on the 2D footage, once in the lab, and two weeks later at home. All PTs were instructed to describe each athlete as “low risk” or “high risk”, which was determined by structured guidelines on the knee position observed. Interrater agreement amongst the PTs was strong, with agreement scores of 87.5%, 90.0%, and 92.5% being achieved, meaning the PTs had meaningful consensus with one another on the assessment of each participant’s knee position. Contrasting the PTs results with a separate 3D analysis done by the researchers revealed strong accuracy, but significant errors, with the PTs not identifying several “high risk” athletes. The results of Ekegren and cohort (2009) suggest that well trained individuals can use 2D analysis to identify potential knee injury risk and attain similar results. However, Ekegren’s group (2009) states precaution should be implemented in the extrapolation of the observations, as 2D does not allow for as thorough of an examination as that of 3D, and crucial identifiers could be overlooked. Ekegren et al. (2009) advocates for the use of 2D as a component to injury risk evaluation, but not the sole methodology.

Mizner and colleagues (2012) collaborated on a similar 2D and 3D comparison to that of Ekegren and colleagues (2009) with n = 36 Division I female athletes. Mizner and team (32) differed from Ekegren et al. (14) by electing to analyze multiple 2D variables, including the fabricated angle between the thigh and shank (frontal plane projection angle: FPPA), and the ratio between the dislocation of the ankle relative to the knee (knee:ankle separation ratio). These data were measured against 3D motion analysis of knee abduction angle and moment during peak knee flexion. Analysis of the data revealed the knee:ankle separation ratio to produce a stronger correlation to the 3D knee abduction angle and moment than that of the FFPA, suggesting the knee:angle separation to be the more useful measurement in kinematic observation. Mizner et al. (2012), similar to Ekegren and cohort (2009), support the use of 2D analysis as a low-cost, effective alternative to 3D analysis of ACL injury risk, however, more research is warranted to produce more reliable evaluation techniques.

Ortiz and cohort (2016) investigated four different 2D lower extremity kinematic analysis techniques in N = 16 (N = 7 female & N = 9 male) participants, with the intention of establishing concurrent reliability scores, to contrast each method for validity against 3D motion analysis amongst three raters. All subjects performed seven trials, five of which were retained, of the DJT from a 40 cm box while being filmed by both 2D and 3D cameras. The four 2D methods of interest to Ortiz et al. (2016) were the knee:ankle separation ratio, knee-separation distance, and two FPPA methods. Knee separation distance quantified the length (in meters) between the right and left patella during initial contact and peak knee flexion. The first FPPA method used a line from the midpoints of the anterior-superior iliac spine (ASIS), patella, and ankle malleoli, which served to measure, by angle, medial or lateral movement of the patellofemoral joint. The second FPPA method used a line from the midpoint of the patella to the midpoint of the ankle malleoli to monitor angular displacement of the knee relative to the ankle. Ortiz et al. (2016) results revealed strong reliability across all 2D methods for all three raters, with the lowest ICC score being .89 for rater 1 in the knee separation distance, while all other tests produced upper 90's ICC scores for all raters. Additionally, the knee:ankle separation ratio and knee separation distance had the strongest resemblance to 3D motion analysis with .96 and .94 ICC scores, respectively. Ortiz and associates (2016) concluded that the knee:ankle separation ratio and knee separation distance are 2D analysis methods that should be strongly considered in the evaluation of ACL injury risk.

A recent advancement in 2D analysis is seen in the novel software program Kinovea, originally created in 2009 and since evolving to serve the ever-growing needs of sport and clinical professionals alike. Puig-Diví et al. (2019) devised an evaluation of Kinovea against the Gold Standard AutoCAD, with the intention of quantifying validity and reliability. A computer-generated model intended to mimic joint positions during motion at 45°, 60°, 75°, and 90° served as the objective analysis medium in AutoCAD and Kinovea for inter- and intra-rater reliability. Collated data revealed that Kinovea is a valid and reliable measure of the selected angles at a 5 m distance, indicated by achieved ICC and r values of 1.00 across all raters and all joint angle positions. Puig-Diví and cohort (2019) do offer caution regarding the results of the investigation, suggesting 90° positions are more favorable to analyze compared to 45°.

Accordingly, the works of Ekegren and colleagues (2009), Mizner and cohort (2012), and Ortiz and associates (2016) support the implementation of the DJT via 2D analysis in the pursuit of investigating lower limb kinematics. The DJT has also been implemented to investigate qualities beyond knee position. Zhang, Xia, Dai, Sun, and Fu (2018) conducted an inquiry into the effects of exhaustion via exercise on lower limb landing strategy, absorption of energy, and joint stiffness in N = 15 college-aged male runners, using 3D motion analysis. Zhang and colleagues (2018) induced fatigue via two protocols a shuttle-sprint test, and a continuous running speed test, performed on separate days to manage exercise interference, with a DJT being completed pre and post fatigue. In the shuttle sprint iteration, participants performed a vertical jump for max height, rested, then completed five vertical jumps, immediately followed by six consecutive 10-meter sprints. The complete shuttle sprint iteration was performed until participants were either unable to achieve 70% of the original vertical jump height in the five jumps or attained 90% of their age-predicted max heart rate. In the continuous running iteration, participants maintained a fixed treadmill speed of 4 m/s until either self-reporting being unable to maintain the speed or attaining 90% of their age-predicted max heart rate. Once fatigue was reached in either exercise condition, participants performed the DJT from a 60 cm platform onto a force plate. Zhang et al. (2018) reported increased landing time and flexion at the knee and ankle from both protocols. Regarding range of motion, movement at the knee was larger post fatigue from the sprint protocol than the continuous running, while ankle displacement only increased from the sprint protocol. With respect to joint moments, knee moments increased from the sprint protocol and decreased during the continuous protocol; ankle moments decreased in both fatigue interventions. The work of Zhang et al. (2018) supports the utility of the DJT beyond knee position in that performance in the test can also be an indication of physical responsiveness to different tasks, which is useful with respect to the interests of this investigation. Synchronically, the discussed literature in this section of the review provides support for 2D analysis of lower extremity motion and acknowledges the DJT being a supported method of recreating motions generally seen in sport and functional daily tasks.

Summary

The intention of this review was to provide thorough support for the implementation of a six-week dynamic warm-up and hip strengthening exercise program with middle school-aged children in the pursuit of improving lower limb kinematics during a DJT. Improving muscular performance has several prerequisites, one of which is a sufficient amount of time devoted to priming the structures to perform the desired functions (McGowan, Pyne, Thompson, & Rattray, 2015; Samson, Button, Chaouachi, & Behm, 2012). Additionally, to ensure optimal return on the time invested, the exercises being devoted to increasing muscular capacitance should closely mirror the expected patterns that will be performed in sport or other functional activities, in accordance with the principle of specificity (Peitz, Behringer, & Granacher, 2018; Ramírez-Campillo et al., 2018). The complex, multi-planar, and, at times, rapidly changing nature of physical activities of youth necessitates physical structures that have a baseline of competency (Ainsworth et al., 2019; Ardern et al., 2018; Haible et al., 2019). Accordingly, structured, effectively taught movement patterns that gradually elevate heart rate, linearly progress in complexity and intensity, and address the requisite needs of the oncoming organized physical activity is a worthwhile consideration in the pursuit of reducing the potential mental and physical obstacles of sport, play, and activities of daily living, which includes the mitigating the risk of harm to the structures (Ainsworth et al., 2019; Ardern et al., 2018; Haible et al., 2019). Presently, a direct, causal relationship between coxofemoral muscle weakness and increased ACL injury risk has yet to be generated. However, a correlation between knee position and the responsibility of the hip muscles in the expression of knee orientation is becoming increasingly apparent (Ardern et al., 2018; Choi, Yang, Jeong , & Lee, 2019; Fabricant & Kocher, 2017; Hewett et al., 2005; Junge, Runge, Juul-Kristensen, & Wedderkopp, 2016; Kambhampati &

Vaishya, 2019; Powers, 2010; Rabelo & Lucaerli, 2018; Siegel, Vandenakker-Albanese, & Siegel, 2012). Further, the interconnected relationship of the structures within and between the lower and upper extremities suggests decrement to one component inflates the responsibility of the auxiliary segments (Cappellini, Ivanenko, Poppele, & Lacquaniti, 2006; Hanawa et al., 2017; Neuman, 2010; Rosen, Ko, Simpson, Kim, & Brown, 2015; Siegel, Kepple, & Stanhope, 2007). Moreover, the hip muscles capacitance for providing ample coxofemoral joint stability while generating substantial force calls for particular attention with respect to maintaining the integrity of the system, while addressing the needs of sport and life. In conclusion, it is the desire of the author to investigate the efficacy of increasing hip muscle performance , measured via the DJT, to contribute to the expanding volume of evidence in the area of youth lower limb injury risk management.

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Appendices

Clinical Biomechanics – Guide for Authors
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Assent Form

Effects of a Hip-Strengthening Program on Lower Extremity Motion During a Drop-Jump Landing in Middle School Children

You are invited to participate in a research study conducted by Dr. Jun San Juan, ATC from the Kinesiology Health and Human Development Department program at Western Washington University. We are attempting to learn about the effects of implementing six weeks of hip strengthening exercises on how you land from a jump from a 12-inch box. With your permission, we would appreciate your participation in our study.

If you decide to participate, you will be asked to fill out a brief form to provide basic information such as age, height and weight. Height and weight measurements will also be taken during the study. Reflective markers will be placed in your hip, knee and ankles to track the motion of your legs. Activities in this study will include you jumping off of a 12-inch box and doing simple exercises that will strengthen your hips.

There is no direct benefit to you by participating in this study. However, the information gained in this study may help the understanding of whether or not the exercises you perform can help improve hip strength. This information could also help other middle school children improve the strength of their hips.

Other people, besides your parents, classmates, and us, will not know you are in our study. We will combine what we learn about you together with what we learn from other middle school children, so no one can tell what came from you. When we tell other people about our research, we will not use your name.

Your parent(s) or guardian(s) must approve you participating in the study. After they decide, you are allowed to choose if you want to do it too. If you don't want to be in the study, nobody will be upset. If you want to be in the study now and change your mind later, that's OK. You can stop at any time.

My telephone number is 360-650-2336 (Dr. Jun San Juan). You can call if you have questions or if you decide you do not want to be in the study any more.

I will give you a copy of this form in case you want to ask questions later.

Agreement

I have decided to be in the study even though I know that I do not have to.

______________________________ ________________

Signature of Study Participant Date

______________________________ ________________

Signature of Researcher Date

Parental Consent Form
Effects of a Hip-Strengthening Program on Lower Extremity Motion During a Drop-Jump Landing in Middle School Children

You are invited to participate in a research study conducted by Dr. Jun San Juan, ATC a professor from the Kinesiology program at Western Washington University (WWU). We are attempting to learn about the effects of implementing six weeks of hip strengthening exercises on landing from a jump from a 12-inch box. With your permission, we would appreciate you and your child's participation in our study. There is no direct benefit by participating in this study. However, the information gained in this study may help in the understanding of the effects of hip-strengthening exercises on landing from a jump, which could provide useful information in the pursuit of improving the hip strength of middle school children.

If you decide you want your child to be in our study, your child will be asked to fill out a brief form to provide basic information such as age, height and weight. Non-invasive measurements will be made throughout the experiment. Activities in this study will include your child jumping off of a 12-inch box and doing simple exercises that will strengthen the hips.

You are assured of the following safeguards to protect you and your child's confidentiality. The files are coded so that your name and your child's name will not appear anywhere on the measures themselves. This signed consent form will be kept in a locked filing cabinet separate from the measures. The video of your child jumping will be kept under a locked data file and deleted once data has been collected. Data collected from this study will only be accessed by the researchers and will be secured at Western Washington University. Your child's data will be destroyed if they withdraw from the study.

Participation in any research study carries possible risks. Because multiple trials will be performed, there is a risk of minimal muscle soreness. However, precautions will be taken to minimize this risk. Your child may discontinue participation at any time during the study. Your signature on this form does not waive your legal rights of protection.

If you have any questions about your child's participation or your rights as a research participant, you can contact the WWU Office of Research and Sponsored Programs at compliance@wwu.edu or (360) 650-2146. If during or after participation in this study you suffer from any adverse effects as a result of participation, please notify Dr. Jun San Juan, (360) 650-2336, Department of Health and Human Development, Kinesiology Program, Western Washington University, 516 High St. MS 9067, Bellingham, WA, 98225, or the WWU Office of Research and Sponsored Programs.

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I have read the above description and understand the expectations for my child's participation.

__ I agree to my child participating ___ I do not agree to my child participating

___________________________________ Date _______________

Parent Signature

____

Parent PRINTED NAME

NOTE: Please sign both copies of the form and retain the copy marked "Participant."

Researcher Copy

Participant Copy

Student Recruitment Transcript

Greetings Everyone!

My name is Blake Corl-Baietti and I am a graduate student at Western Washington University. Myself and my colleagues are requesting your permission to guide you through six weeks of hip-strengthening exercises. You will be asked to do a drop-jump test before and after the six weeks of exercises. This would require you to be filmed and wear reflective markers on your clothes. The film will only be seen by us and will be destroyed after we collect what we need. Your participation is entirely up to you and we want you to make the best choice for yourself. Please take these forms home to your parents to fill out together and make your decision. Thank you for your attention!

Intake Form

Subject ID	Age	Height (cm)	Weight (kg)	Dominant Limb	Activities