Response of vertical jump height in female athletes 10-14 years old to a lower body strength training program

by

Richard Sylvester

A Thesis submitted to the Faculty of Graduate Studies of

The University of Manitoba

in partial fulfillment of the requirements of the degree of

Master of Science

Faculty of Kinesiology and Recreation Management

University of Manitoba

Winnipeg

Abstract

Strength training is safe and effective for children according to a position statement by the National Strength and Conditioning Association (2009). One such effect or benefit can be increased vertical jump ability. Due to methodological inconsistencies, determining whether strength training consistently leads to increased vertical jump has been difficult to do. This randomized study involved a 12-week, two-time per week lower body strength training program for the intervention group, and an upper body strength training program for the control group. A countermovement jump tested at baseline and post-intervention by a blinded observer measured the effect of this training intervention on the vertical jump ability of 10-14 year old athletic females (n=36). The results revealed no significant changes within each group from baseline to post-intervention and no significant differences between each group. It appears that a number of factors may have influenced the results of this study not the least of which was the high baseline ability of the participants. More research using strong methods, a sufficient training stimulus and female children is needed in order to clarify the response of vertical jump to a resistance training intervention.

Acknowledgements

First off I wish like to thank my advisor Dr. Michelle Porter for accepting me as a student after a six-year absence from post secondary education. I am also grateful for her placing me in a resistance training project with a very relevant topic to my career as a Strength and Conditioning coach. The attention to detail in her guidance was very much appreciated.

My gratitude is extended to Joanne Parsons, the lead researcher in this resistance-training project. She had the unique perspective of being a student herself as well as a mentor for me. Her advice scholastically and personally was very much appreciated.

I wish to thank my committee members Dr. Phillip Gardiner and Dr. Sandra Webber for their help and guidance as well as their very approachable nature. I always felt they were there for me and challenged me appropriately.

I wish to thank my parents for their support throughout every step of the way. I love you mom and dad. My gratitude is extended to one of my oldest friends Tyson Jones helped me decide to apply for my masters, which is one of the best decisions I have ever made. A special thank you to my lab mate Glenys Smith for helping me with statistics.

My appreciation is also expressed to my employers Dana Way and Adrian Honish from Effectus Athlete Development and Matt Barr from the University of Manitoba for the tremendous amount of help they gave me throughout this process. I would also like to thank Dr. Dean Kriellaars, Alex Gardiner and Terry Hadlow for serving as my mentors in school and work.

It would be remiss of me not to thank every client I have ever had. Each client is a learning experience that lends to future success with other clients. Thank you to all the participants in the study, without these participants we literally could not have done the study.

Table of Contents

List of Tables

List of Figures

Definitions

Children

Children is a term that refers to people under and including the age of 14 years old (Hill and Hill 1981-2005).

Concentric Contraction

During concentric contractions, a muscle is activated to produce tension that results in a shorter muscle length (Webber 1996). An example of a concentric contraction is the ascending portion of the biceps curl exercise.

Countermovement Jump

The countermovement jump is a ballistic movement that involves starting in a standing position then rapidly lowering the body (Bobbert and Casius 2005) in the direction of knee, hip and trunk flexion. Shortly thereafter the body is raised in the direction of knee, hip and trunk extension where the body will then leave the ground.

Eccentric Contraction

During an eccentric contraction, a muscle is activated to produce tension that results in a longer muscle length ((Miller, Cheatham, and Patel 2010, 671-682). An example of an eccentric contraction is the descending phase of the biceps curl exercise.

Isometric Contraction

During an isometric contraction, the muscle produces tension but does not produce a change in muscle length (Nordin and Frankel 2001). An example of an isometric contraction is the start position prior to squatting.

Mechanical Work

"Mechanical work is defined as the product of propulsive force production and the distance that an object is moved" (Edwen et al. 2013, 7).

Plyometric Exercises:

Plyometric exercises involve exercises that cause muscles to quickly lengthen and then quickly shorten in the opposite direction (Johnson, Salzberg, and Stevenson 2011). Lower body plyometric exercises include variations of jumping, hopping and bounding. Upper body plyometric exercises include variations of tosses, throws, and pushups.

Repetition Maximum

A repetition maximum represents the maximum load that can be successfully lifted with proper form for a given number of repetitions (Faigenbaum et al. 1993). An example is a 1RM (one repetition maximum) test where the maximum load that can be successfully lifted once with adequate form is recorded.

Resistance training:

Resistance training is defined as a "type of exercise that requires the musculature to contract against an opposing force generated by some type of resistance" (Behringer et al. 2010, e1200). Resistance training can produce changes in muscular strength, power, muscle hypertrophy, local muscular endurance, or a combination thereof " (Miller, Cheatham, and Patel 2010, 671-682).

Squat Jump

The squat jump is a ballistic movement that involves starting in a position of knee, hip and trunk flexion (Bobbert et al. 1996) then rapidly moving in the direction of extension of the knee, hip, and trunk moving the body upwards in order to leave the ground.

Strength

Strength can be defined as the ability of the neuromuscular system to "exert or resist force" (McCambridge and Stricker 2008, 835-840).

Strength Training

Strength training includes the "use of resistance methods to increase one's ability to exert or resist force. The training may include use of free weights, the individual's own body weight, machines, and/or other resistance devices to attain this goal" (McCambridge and Stricker 2008, 835-840).

Youth

Youth is a term that refers to people aged 15-24 (United Nations Program on Youth, 2011).

Introduction

It is known that participation of children in sports can be a very positive experience in the short term and the long term. The message continues to be spread, which is indicated by an increase in participation among children in sports (Young and Metzl 2010; Myer et al. 2011). As participation in sports continues to grow, so has the importance and desire for improved sports performance and injury reduction (Myer et al. 2011). Participation of children in strength and resistance training continues to grow as well. Children have been increasingly participating in school-based strength and resistance training programs as well as fitness centre-based strength and resistance training programs (Faigenbaum and Myer 2010; Myer et al. 2011). The research advocating for the safety and effectiveness of strength training for children has been extensive and is very strong (Faigenbaum et al. 2009; Faigenbaum 2000, Myer et al. 2011; Young and Metzl 2010; Miller 2010; Ignjatovic et al. 2009; Faigenbaum and Myer 2010; Malina 2006; and Behm et al. 2008; McCambridge and Stricker 2008; Behringer et al. 2010). The research on the effectiveness of strength training for improving sports performance factors (i.e., injury reduction, vertical jump height) is a bit more ambiguous. Methodological differences often create this ambiguity leading to some studies supporting strength training's effectiveness at improving factors like vertical jump height (Faigenbaum et al. 1993) and injury reduction (Cahill and Griffith 1978) and others being less clear on the effectiveness of those same factors; vertical jump height (Faigenbaum et al. 2002), and injury reduction (Heidt et al. 2000). With this increased participation it is important that the research strongly supports all the benefits and safety that strength training researchers and professionals claim. Research on the response of vertical jump height to strength training is not as extensive in children as it is in adults. There is even less research on females exclusively performing strength training to improve vertical jump height which often leads to adult study findings being applied to children in practical settings inappropriately. The methodological differences like differences in training intervention length, testing methods and participant gender also create further issues when trying to interpret results of studies of children. Thus, the rationale of this study is to examine vertical jump height responses of athletic females to a strength training intervention targeting the lower body.

1. Review of Strength Training Literature

1.1 Safety and Efficacy

Despite findings in the past of strength training being unsafe for children by such reports as the US Consumer Product Safety Commission (CPSC) National Electronic Injury Surveillance System (1979, 1987), closer examination of such reports reveals a different story. The previous reports did not state the true causes associated with most of the injuries. Therefore if a child were to get hurt "weightlifting" it would not be distinguished whether they were "horsing around by themselves" or lifting weights in physical education class for example. When examining the reports of injuries associated with lifting weights, a large portion are due to hand pinching, weights being dropped on the feet or improper and unsafe weight room habits. For example a more recent US CPSC National Electronic Injury Surveillance System from 2002 to 2005 reported on resistance training in three age groups 8-13, 14-18 and 19-22. Two thirds of reported injuries were due to dropping and pinching injuries in children 8-13 years old. The remaining injuries were growth plate injuries, lower back injuries, fractures (most in younger groups), and strains and sprains, in which most happened with older age groups (14-18 and 19-22). Improper progression of loads leading to lifting loads beyond their capability, lack of supervision, and improper form are often the causes of these other injuries (Myer et al. 2011;

Faigenbaum 2000). Appropriate instruction including safety precautions, proper exercise and spotting techniques can help reduce these types of injuries along with proper supervision (Myer et al. 2011; Faigenbaum and Myer 2010). Zaricznyj et al. (1980) revealed that injuries due to resistance training had low incidence compared to other sports and activities. Zaricznyj et al. (1980) also revealed that "0.7% of 1576 injuries" were due to resistance training, whereas football and gymnastics accounted for 19% and 13% of injuries respectively. A report by Burt and Overpeck (2001) revealed similar results with exercise related injuries (weightlifting, aerobics, gym class, track and field, jogging) accounting for 0.8% of injuries. Injury rates in strength training studies have also remained low. The safety of resistance training in children and youth was examined in a review of intervention studies (Faigenbaum and Myer 2010a, 56-63). This study reviewed 27 resistance-training studies and found only three injuries. The injury rate was 0.055 to 0.176 per 100 hours of participation, which are very encouraging rates.

Strength training in children has been shown to be effective at increasing strength. Meta analyses reporting on the effect of strength training on increasing strength in children have shown effect sizes of between 0.57 and 0.75 (Falk and Tenenbaum 1996; Payne, Morrow Jr., and Dalton 1997) indicating a moderate to large effect. According to a position stand by Faigenbaum et al. (2009), strength training can, more specifically lead to significant increases in strength above and beyond normal growth and development. This is true as long as safety is a primary concern by adhering to proper strength training guidelines.

A position stand by Faigenbaum et al. (2009) describes some guidelines appropriate for children performing strength and resistance training. Providing "qualified instruction and supervision" (2009, s70) will help ensure there is a primary focus on technique, that training loads are progressed in a safe and appropriate manner, that the environment is safe, and concerns are being met. Proper warm up, cool down, and proper recovery methods are also important factors in strength training for children. The previous beliefs of the ineffective and unsafe nature of strength training for children have clearly been proven unfounded. Strength training for children is both safe and effective, which may lead to other benefits to be discussed in the proceeding section.

1.2 Benefits of Child Strength Training

Strength training that is properly planned and implemented as well as competently supervised can lead to many benefits. Benefits associated with child strength training are improved local muscular endurance (Behm et al. 2008; Ignjatovic et al. 2009; Malina 2006), improved motor performance especially when combined with specific training (Behm et al. 2008; Ignjatovic et al. 2009; Faigenbaum 2000; Faigenbaum et al. 2009), improved body composition in obese children when combined with proper diet (Behm et al. 2008; Ignjatovic et al. 2009; Young and Metzl 2010; Faigenbaum 2000; McCambridge and Stricker 2008, Faigenbaum et al. 2009), enhanced mental well-being (Ignjatovic et al. 2009; Faigenbaum 2000; McCambridge and Stricker 2008), improved cardiovascular risk profile (Ignjatovic et al. 2009; Young and Metzl 2010; McCambridge and Stricker 2008), and improvements in strength and density of bone when combined with impact loading (Ignjatovic et al. 2009; Young and Metzl 2010; Faigenbaum 2000; McCambridge and Stricker 2008).

An additional benefit in children of including properly planned, implemented and supervised strength training as part of a preparatory system, is that it can help “increase resistance to sports related injuries” (Faigenbaum et al. 2009 s68). The way this appears to be accomplished is by strengthening key muscles to decrease weakness and address previous injury (Faigenbaum and Myer 2010). However, studies using only strength training exercises as a preventative measure against sporting injuries are extremely scarce for children. Database searches turn up studies involving a holistic approach, by combining strength training exercises, plyometric exercises, balance exercises, agility exercise, and core exercises. Furthermore these studies have more to do with improving movement biomechanics often associated with injuries and not direct evidence of injury reduction. An example is a study by DiStefano et al. (2009) who divided a large group of participants (ages 10-17) and randomly assigned them to one of two training programs. The results revealed that the older (high school/youth) participants showed more improvements than the younger (pre high school/Children) participants. Furthermore, participants with the most movement errors at baseline showed more improvements than others with fewer movement errors. Therefore older children and youth have produced larger improvements with injury prevention programs compared to young children. These results may suggest that younger children may require different injury prevention programs than youth. Hejna et al., compared the “injury rate and time lost due rehabilitation” (1982, 28) of male and female athletes doing strength training and conditioning against those of a control group. Overall, the training group had an injury rate of 26.2% compared to a rate of 72.4% in the control group (Hejna et al. 1982). Time lost to rehabilitation per number of athletes overall was 2.0 days for the training group and 4.8 days for the control group. More research is needed to more clearly determine whether strength training for injury prevention purposes also extends to children below age 13. It does appear that, for children aged 13 and 14 as well as youth; strength training is effective when combined with other types of training.

Along with increased sport participation among children, there is increased participation in school and fitness centre based strength and resistance training (Faigenbaum and Myer 2010; Myer et al. 2011). Improved sports performance is a major goal for those children undertaking strength training, in the hopes that the child can maximize their sporting ability and perhaps further their sporting career. In children, motor performance can improve as a result of strength training (Behringer et al. 2011). Examples of motor performance measures that may be improved by strength training alone, are sprint speed measured by the 40 yard dash (Hetzler et al. 1997), horizontal jumping ability measured by a standing long jump (Lillegard et al. 1997), and upper body strength/power measured by medicine ball throws (Santos and Janeira 2012). Motor performance measures can also improve as a result of strength training combined with sports related skills (Behm et al. 2008; Ignjatovic et al. 2009; Faigenbaum 2000; Faigenbaum et al. 2009). Where individual performance based sports are concerned, improvements are readily apparent with an improved time or increased distance. With team sports it is harder to assess improvements in sports performance, since success in team sports is not measured like it is with individual performance based sports. With the popularity of professional sports, it is no wonder that parents and their children want to maximize the child's sporting ability and perhaps prolong their sporting career.

1.3 Differences in Responses to Strength Training

Differences in responses to strength training can be caused by "age, level of maturation and sex" (Malina 2006). When examining studies of strength gains among children, it is revealed that a good number of these studies use non-athletic children and use grip strength as the measure of interest (Blimkie and Sale, 193-224). Acknowledging the differences in responses is important when examining or reporting on study results.

1.3.1 Effect of Age

A meta-analysis by Behringer et al. (2010) revealed that strength gains show a slight increasing trend with age. According to Sandercock et al. (2013), age is related to gains in strength for children as well as youth. The study revealed that relative grip strength in males was higher for participants born earlier in the year. This same relationship was not revealed in females. It is possible that age along with other factors will have a larger influence on strength just like it does for vertical jump (Aouichaoui et al. 2012). Age also influences the ability of the body to recover from exercise (Bottaro et al. 2011). Children and youth both showed declines in peak torque from set one to three, but only youths showed significant declines. In short, children appear to recover at a faster rate compared to youth.

1.3.2 Effect of Maturation

When examining maturation-related differences in strength gains, it is important to distinguish between relative and absolute changes, in order to interpret results properly. Absolute gains in strength are superior in postpubescent and pubescent children and youth compared to prepubescent children (Faigenbaum et al. 2009; Blimkie et al. 1992). A review by Faigenbaum (2000) and Malina (2006) reported that overall, prepubescent *relative* strength gains match and sometimes exceed gains made during pubescence and postpubescence. These findings are in agreement with a review by Blimkie and Sale that stated that, prepubescent children show "comparable and sometimes greater relative strength" (1998, 212) gains compared with pubescent and postpubescent individuals. Therefore as a person matures into their pubescent and postpubescent years, absolute gains exceed that of prepubescent years and relative gains are no greater or do not match those obtained during prepubescent years.

1.3.3 Effect of Gender on Strength Gains

A study by Malina (2006) reported that gender differences in strength gains between prepubertal males and females are either not present or show very small differences. However, Lillegard et al. (1997) showed significant gender differences in two of six strength training exercises, with the males showing significant gains compared to females. The two exercises were lat pull downs and leg extensions. As noted in a review by Blimkie and Sale (1998, 193-224), prepubescent females and males have rates of strength increases that are similar, but with males having higher absolute strength. During puberty, females tend to increase slightly in their rate of strength gain and then plateau after puberty. This is different from males who show similar rates to females during prepubescence, then an acceleration in rate of strength increase during puberty with a slowed but continued upward trend during postpubescence. Therefore, starting at puberty, gender differences begin to show, continuing with the postpubescent plateau in females, and the diminished but continued increase in males.

1.4 Strength Training Resistance Modes

When examining the different child strength training studies, it is apparent that a variety of resistance modalities have been used. Examples are variable resistance machines (Santos and Janeira 2012; Ramsay et al. 1990), free weights (Ozmun, Mikesky, and Surburg 1994), and hydraulic machines (Weltman et al. 1986). Variable resistance devices tend to change the resistance lever arm (Walker et al. 2012) or resistance profile (Aboodarda et al. 2012) in accordance with the changing moment arm of the human limb (Kulig, Andrews, and Hay 1984). Examples are cam-based equipment, rubber bands (Aboodarda et al. 2012), and chains (McMaster et al. 2009). Constant external resistance devices involve a constant mass (Walker et al. 2013) but a load that changes throughout the range of motion due to the changing lever arm of the resistance, changing moment arm of the human limb as well as the acceleration of the load throughout the range of motion (McMaster et al. 2009). Examples include free-weights and round wheel cable machines (Manning et al. 1990).

1.5 Child Strength Training Parameters

Recommended strength training parameters for children differ from that of adults, in that adults can more safely train closer to maximal intensities in order to increase their strength (Cormie, McGuigan, and Newton 2011). Due to the growth and maturation status of children, they cannot be trained the same for fear of injury. Strength training volume and frequency for children should be lower compared to adults (Faigenbaum and Myer 2010b, 161-168) in order to decrease over-training, which can lead to injuries. A position stand by Faigenbaum et al. includes recommended strength training parameters of "one to three sets of 6-15 repetitions of various upper and lower body strength exercises" (2009, s70). These upper and lower body exercises should be performed two to three times per week " on non-consecutive days" (2009, s70). In comparison, adults are recommended to perform one to three sets of eight to twelve repetitions for novice, and three to four sets for intermediate and advanced (Ratamess et al. 2009). These exercises in adults should be performed two to three days per week for novice, three to four days per week for intermediate and four to six days per week for advanced participants (Ratamess et al. 2009). It is important to recognize the differences in responses to strength training among various ages, gender and levels of maturation in order to ensure proper guidelines are being implemented to ensure a safe and efficacious experience for the children participating. Near maximal loads in order to increase strength are generally not recommended for children like they are for adults (Cormie, McGuigan, and Newton 2011) due to potential for injury (Faigenbaum 2009). With novice lifters, especially children, it is generally recommended that a larger number of repetitions per set and a lighter load be completed in order to learn proper exercise technique (Faigenbaum et al. 2009). Once proper technique has been learned, loads can be progressed in a safe manner (repetitions decreased as a result) up to 5-7 RM (Ramsay et al.

1990). Adult training loads need to be progressed safely as well, but due to their more mature status, the progression can be a bit more aggressive (Faigenbaum 2000).

2. Vertical Jump

Vertical jumping ability is important for many sports skills like rebounding in basketball, spiking and blocking in volleyball, and high jump and long jump in track and field (Ashley and Weiss 1994). Higher vertical jumps can provide an advantage in team sports and can determine placing in individual sports. The vertical jump (VJ), in particular the countermovement jump, involves a complex interaction of forces and joint movements each contributing to the height of the jump. Other types of vertical jumps include: the squat jump (jump from a crouch), drop jump (jumping from a height) and reactive jump (repetitive jumps for a period of time). The countermovement jump though, will be the jump of interest in this study. Figure 1 outlines the complexity of a countermovement jump without arms.

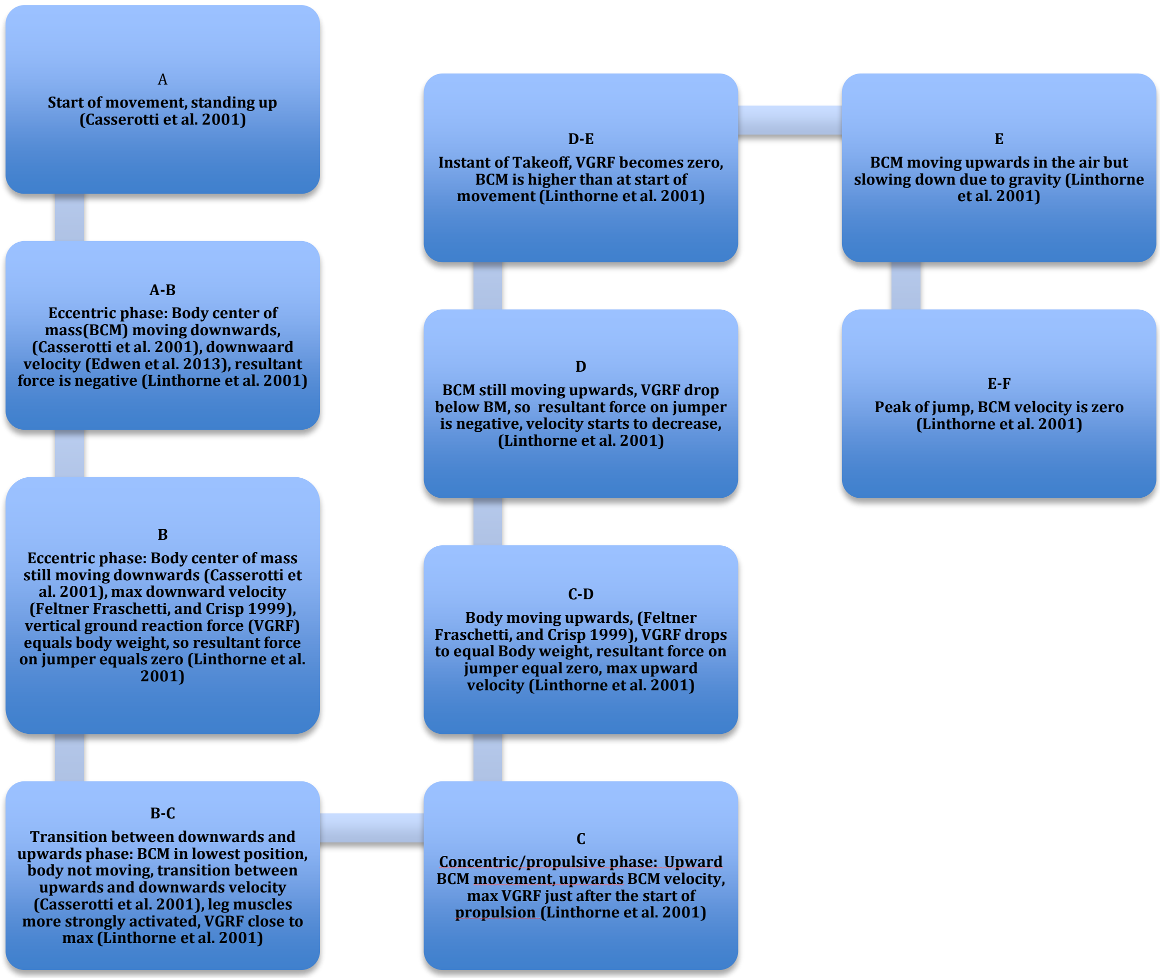

Figure 1: Series of events in a countermovement jump. Note: BCM= body centre of mass; VGRF=vertical ground reaction force; BM=body mass; max = maximum.

2.1 Determinants of Vertical Jump Ability

2.1.1 Force

A vertical jump is affected by the force generating capabilities of the primary muscles involved in jumping, namely muscles around the hip, knee and ankle (Ashley and Weiss 1994) and trunk (Lees, Vanrenterghem, and Clercq 2004, 1929-1940). The force generated by these muscles will produce an equal and opposite vertical ground reaction force. As Lees, Vanrenterghem, and Clercq note, peak vertical ground reaction force occurs around 90% of movement time (countermovement jump with arms) and approximately 70-75% movement time (countermovement jump without arms) (2004, 1929-1940). Despite the relationship of force and vertical jump height, peak force does not tell the whole story. Kirby et al. (2011) found that peak force and countermovement jump height do not have as strong a relationship (r=0.39) as vertical jump and net vertical impulse (r= 0.92) when examined according to depth of crouch before a vertical jump. In other words, the amount of force generated over a certain range of motion, and not just the peak value attained will affect jump height. Knowing how forces and movements affect the vertical jump can help researchers and practitioners train athletes to maximize vertical jump height by helping to focus training efforts.

2.1.2 Velocity

The velocity of the body center of mass, namely takeoff velocity (Lees, Vanrenterghem, and Clercq 2004, 1929-1940) and peak velocity (Kirby et al. 2011) also influence vertical jump height. During a vertical jump, the use of a countermovement (Bobbert and Casius 2005) and its depth (Kirby et al. 2011) along with the use of arms (Lees, Vanrenterghem, and Clercq 2004, 1929-1940) will affect the takeoff velocity. Kirby et al. (2011) showed that peak vertical velocity increased with each increasing crouch depth and showed a positive linear relationship with countermovement and squat jump heights. Lees, Vanrentergham and Clercq (2004) also found that peak vertical velocity of a countermovement jump (with arms) occurred near the end of the ascent phase (past 90% of movement time).

Interestingly, arms affect the vertical velocity but not until late in the propulsive phase (after 92% movement time). Harman et al. (1990) demonstrated that peak vertical velocity occurred at around 0.03s before takeoff in a countermovement jump (similar to three other jump types). Hara et al. (2008) showed that a countermovement jump with arms produced higher vertical velocity of the body centre of mass than a countermovement jump without arms and a squat jump with and without arms.

Although the above-mentioned conditions should maximize vertical jump height, these conditions are not always possible during sports, so their worth should be interpreted with caution.

2.1.3 Impulse

The product of force and time is called impulse, which acts on a body or object and causes a change in momentum (Kirby et al. 2011). Impulse during a vertical jump will lead to a displacement of the body centre of mass upwards. An impulse can be a small force applied for a longer time or a large force applied quickly. Since force can only be produced while the feet are in contact with the ground, there is no time to produce a small force impulse; therefore a large force has to be developed quickly (Linthorne 2001). Kirby et al. (2011) revealed that relative net vertical impulse during the propulsive phase increases with increasing squat depth. Jump height increased incrementally with each squat depth: 0.15m, 0.30m, 0.45m, 0.60m, and 0.75m. A larger depth allows for more time to accelerate, thus a larger jump (Kirby et al. 2011). Since both movements start from zero velocity (squat jump and countermovement jumps), but one (countermovement jump) ends with a higher velocity this means a larger change in velocity took place with a constant mass, in other words, a larger change in momentum. Relative net vertical impulse was shown to be a good predictor of countermovement jump height (r=0.92) (Kirby et al 2011) and squat jump height (r= 0.93) (Kirby et al. 2011). Relative net vertical impulse appears to be a fairly consistent way of explaining differences in jump performances across a group of individuals. However it does get overlooked in favor of power in a lot of vertical jump studies

(Kirby et al. 2011).

2.1.4 Arm Swing

The use of arms during a vertical jump can provide a higher vertical jump than if the arms were not used in squat jumps and countermovement jumps (Harman et al 1990). Countermovement jumps with arms were shown to be 17.6% higher than countermovement jumps without arms (Hara et al. 2008). During countermovement jumps, one of the reasons why the use of an arm swing increases performance in the vertical jump is because it leads to an increase in takeoff velocity and thus the body's centre of mass moves faster at the takeoff point. This is likely due to a larger degree of trunk, hip, knee, ankle bending (Edwen et al. 2013; Lees, Vanrentergham and Clercq 2004) which increases force (impulse) produced by the important jumping muscles and vertical ground reaction force to a greater extent and later in the propulsive phase (Hara et al. 2008). Feltner, Fraschetti, and Crisp (1999), found a 12.7% increase in vertical velocity when using arms vs. not using arms, whereas Lees, Vanrenterghem, and Clercq (2004) found a 8.9% increase in vertical velocity (P<0.001). An additional reason for the increase in performance when using arms is the increase in the height of the body centre of mass at takeoff (Feltner, Fraschetti, and Crisp 1999; Lees, Vanrenterghem, and Clercq 2004). It was revealed that there was an average of a 6.1 cm increase in the height of the body centre of mass at takeoff. The use of a jump with arms or without arms will likely depend on the research question. If the goal is strictly to assess the maximum jump height of a participant, which will likely require more body coordination (Klavora 2000), then the use of arms is recommended. If the goal is to assess the effectiveness of a lower body strength training intervention on vertical jump height, it is preferable to decrease the factors that are difficult to measure (Markovic et al. 2004), so a jump without the use of arms is recommended.

2.1.5 Countermovement

Countermovement jumps, regardless of the use of arms, produce higher jump heights than squat jumps (Bobbert et al. 1996). Hara et al. (2008) demonstrated a 9.2% increase in countermovement jump with arms over squat jumps with arms. The muscles are able to generate higher forces (moments) before the propulsive phase begins (Bobbert et al. 1996) which leads to more work done by the muscles during the start of the propulsive phase (Bobbert and Casius 2005; Hara et al. 2008). In other words, during a squat jump, part of the propulsive phase is used in order to generate high enough moments for the body to leave the ground, whereas during a countermovement jump a high moment is generated earlier (more time to develop force due to countermovement) leading a larger impulse (Kirby et al. 2011) and increased acceleration (Casserotti et al. 2001) during the propulsive phase. Increasing these factors ultimately leads to a greater takeoff velocity and thus higher jump (Lees, Vanrenterghem, and Clercq 2004). There are numerous potential but also questioned mechanisms of increased jump height in countermovement jumps vs. squat jumps, namely; storage and utilization of elastic energy, potentiation of contractile elements, the interaction of contractile and elastic elements, and increased stretch reflexes (Cormie 2009). All of these other potential mechanisms ultimately lead to either more force at the start of the propulsive phase or greater velocity at takeoff (Cormie 2009). The validity and contribution of each however is up for debate (Cormie 2009). Performing jumps with a countermovement will lead to a higher jump, a fact that should be taken into consideration in research and sporting settings.

2.1.6 Anthropometric, Age, and Gender Effects

It is important not to overlook the contribution that body differences, age and gender make in the performance of a vertical jump. These factors may help explain differences amongst participants. A stepwise regression by Aouichaoui et al. (2012) showed that four factors (standing height, body mass, fat free mass and age) accounted for a significant portion of the variability of countermovement jump height for males and females (r square of 0.36 for males and 0.26 for females). Furthermore, Aouichaoui et al. (2014) revealed that neither standing height, sitting height, body mass, fat free mass, body fat, leg length or waist size could solely predict countermovement jump height (using photocell) in 407 children aged 7-13. Taylor et al. (2010) showed that males demonstrated significant jump height differences compared to females from 11 years of age onwards, with significant increases year after year from 10 years of age to 14 years of age (Taylor et al. 2010). Females showed significant increases in jump height from about 10 years of age to 12 years of age, which was followed by a plateau (non-significant increase or non-significant decrease. These trends appear to follow a similar pattern to strength gain differences in females and males, where females show an increase then plateau and males show significant increases followed by diminished but continued increase. Therefore, these factors need to be considered when examining vertical jump height.

2.1.7 Procedural Factors

Some general factors that can affect vertical jump tests are fatigue due to activity prior to testing, motivation (Thorlund et al. 2008) and familiarization to the testing procedures (Chelly et al. 2009). A child that is fatigued or not motivated is not likely to produce a maximum jump at the time. Children tend to show a learning effect in motor activities like vertical jump and lifting weights (Rutherford and Jones 1986; Ramsay et al. 1990), which can be accounted for by changes in skill and coordination. Due to this learning effect, there is often a period of time needed to get used to the activity. Familiarization jumps prior to testing are usually prescribed, in order to diminish the learning effect with successive jumps.

2.2 Vertical Jump Testing

Testing and evaluation are important for research as well as practical settings like strength and conditioning facilities, rehabilitation facilities or school physical education programs. Some reasons why testing is important are motivation, improved prescription of exercise, selection for sports teams, determination of program/teaching effectiveness, improved compliance from participants and parents, reinforcement of research results, and collection of norms for comparison (Baechle and Earle 2000, 276).

2.2.1 Vertical Jump Measurement Devices

The countermovement jump has been used in conjunction with many different devices which all have their advantages and disadvantages. The subsequent sections will outline a few of the devices.

2.2.1.1 Belt Jump

The University of Toronto Belt Jump (Sport Books Publisher, Toronto, ON) formerly known as the Abalakov Belt Jump, consists of a measuring tape attached to a belt worn by the participant at one end with the other end of the tape attached to a mat with a tape feeder (Klavora 2000). The belt worn by the participant is attached approximately at the level of the centre of mass. Just like the Abalakov Belt Jump, the length of tape pulled out after a jump represents the height of the jump (Klavora 2000). When examining the criterion validity of four vertical jump devices, Buckthorpe, Morris, and Folland (2012) found that the Belt Jump produced measurements within 1 cm (calculated from force plate software) of the criterion method (Laboratory Force plate) and was determined to be a valid ($r=0.93$) measure of vertical jump height.

Reliability has also been demonstrated for the Belt Jump (Slinde et al. 2008), but only in adults. Slinde et al. (2008) measured test-retest reliability of three different versions of countermovement jumps and determined that a countermovement jump using the Belt Jump (with arms) had good relative reliability for men (ICC= 0.79) and only moderate relative reliability for women (ICC=0.48) when tested on average four to fourteen days apart. There were a larger number of men than women in the study, possibly leading to better reliability amongst men than women. Markovic et al (2004), sought to compare the reliability of a Squat Jump and Countermovement Jump using the Belt Jump with and without arm swing. This study determined that Belt Jumps with and without arm swing had good relative reliability with an ICC of 0.93 and 0.94 respectively for men. The absolute reliability for the Belt Jump with arms (CMJ) had a coefficient variation of 4.6% and 4.1% without arms. Differences in reliability values could possibly be due to participant number, which were 30 in Slinde et al. (2008) and 93 in Markovic et al. (2004). Participant exercise experience could have had an influence, with less experienced non-physical education students and friends of the author in Slinde et al. (2008) and active physical education students in Markovic et al. (2004).

The biggest advantage of a Belt Jump device is its assessment of vertical jump height based on the body centre of mass due to the belt’s placement around the waist (Klavora 2000). Other advantages of the Belt Jump include ease of measurement, transport and storage. A possible disadvantage is the fragility of the device. Upon inspection, it appears that it might break easily. In addition, extra pelvic motion at the apex of the jump might also affect the jump (Starosta and Radzinska 2001).

2.2.1.2 Jump and Reach Tests

Other common field tests are the jump and reach tests in which vertical jump height is represented by the difference between standing reach height and jump height (Kirby 1991).

Equipment used includes a jump board, chalkboard or Vertec (Sports Imports, Hilliard, OH), which is an adjustable stand with moveable pieces each representing a different height (Klavora 2000). The Vertec has been deemed a valid measure of vertical jump ability (r=0.91) according to Buckthorpe, Morris, and Folland (2012). The Vertec has also been found to be a reliable measure of vertical jump height (Nuzzo 2011), with intra-session reliability of 0.87-0.89 for females and 0.94 for males. Intersession reliability was calculated to be 0.80 for females and 0.90 for males. A possible advantage of a jump and reach test is external motivation of something to reach for in order to produce a maximum jump. A possible disadvantage is the increased level of coordination needed to complete the jump and reach, and the amount of space required.

2.2.1.3 Contact Mats

The contact mat or platform has embedded devices attached to a computer that displays time in the air and height of the jump (Bosco, Luhtanen, and Komi 1983). It has been deemed to be a valid test of vertical jump ability (r=0.90) according to Buckthorpe, Morris, and Folland (2012). Nuzzo, Anning, and Scharfenberg (2011) calculated the intra-session reliability to be 0.90-0.93 for females and 0.92-0.93 for males, whereas intersession reliability was calculated to be 0.92 for females and 0.84 for males. The disadvantage of this method is getting the participant to land in the same position as they jumped from. Since the only measurable factor is time in the air, a crouched position upon landing can increase time in the air and hence overestimate vertical jump height (Nuzzo, Anning, and Scharfenberg 2011).

2.2.1.4 Force Platforms

Force platforms, measure peak and average ground reaction force with respect to time (Lloyd et al. 2009). Using special software, jump height is calculated automatically.

Furthermore, the advantage is accuracy of measurement throughout the eccentric and concentric phases. Disadvantages are the complexities of the software and the expense. Force platforms have been used to measure criterion validity in Buckthorpe, Morris, and Folland (2012).

2.3 Effectiveness of Resistance Training on Vertical Jump Performance

Factors that affect vertical jump responses to resistance training (including strength training) are: the intensity of the movement (load, force), the volume of training, frequency of training sessions, type of exercise, the duration of each exercise session, rest period between exercises, velocity of the movement, range of motion of the movement, and type of equipment (Ratamess et al. 2009).

2.3.1 Influence of Strength Training

The above-mentioned factors can interact to influence a fitness trait. One such example is the interaction of the intensity (load, force) of the movement and the velocity of the movement. As the force required for producing the movement increases, the velocity with which it can be performed will decrease (Kawamori and Haff 2004). The ability to express a high level of force (strength) (Kawamori and Haff 2004) will affect performance of motor tasks through its influence on things like the force-velocity relationship (Toji and Kaneko 2004) and impulse (Cormie 2009). Examples of strength exercises are squats, lunges and leg press. Essentially, increased strength will alter the relationship between force and velocity so that for a given level of force, the velocity of that movement will be larger (Toji and Kaneko 2004). The effects of strength training interventions in children as well as youths were assessed in a systematic review and meta-analysis by Harries, Lubans, and Callister (2012) where significant improvements in vertical jump performance due to strength training interventions were shown (P=0.05). The meta-analysis ultimately concluded that strength training could lead to increased vertical jump ability, although they provided caution in interpreting the results due to the potential for bias and the heterogeneity in the findings.

2.3.2 Influence of Velocity

When considering exercises that can influence the velocity component of a jump, explosive methods like plyometric jumps have been examined (Kotzamanidis 2006). Rubley et al. (2011), Potdevin et al. (2011), and Meylan and Malatesta (2009) demonstrated increases in vertical jumping ability after a plyometric training period. Reasons for improvement could be due to the similarity of the movements and the similarity in velocity between these exercises and vertical jumps (Meylan and Malatesta 2009). In a recent meta-analysis Harries, Lubans, and Callister (2012) concluded that plyometric interventions could lead to increased vertical jump ability.

2.3.3 Influence of Combined Methods

Combined methods like weighted jumps influence the velocity component of the vertical jump as well as the force component (Cormie, McGuigan, and Newton 2011). Weighted jumps have the advantage of increasing the force applied to the ground (Cormie, McBride, McCaulley 2008) while still moving quickly. This advantage differs from a squat, which has a high force component and a low velocity component (Kawamori and Haff 2004) or a squat jump that has a high velocity component and low force component (Kirby et al. 2011). Combined methods can also involve strength training methods and plyometric methods in the same time period, which have also shown positive effects (Santos and Janeira 2008; Myer et al. 2005; Wong, Chamari, and Wisløff 2010; Faigenbaum et al. 2007). In addition, a meta-analysis by Harries, Lubans, and Callister (2012) concluded that combined method interventions could also lead to increased vertical jump ability.

2.3.4 Effectiveness of Strength Training on Vertical Jump Performance in Children

The literature regarding the effect of strength training on vertical jump ability is not consistent or vast with children aged 10-14 years old (see Tables 1 and 2 for details). After examination, child strength training studies by Christou et al. (2006), Hetzler et al. (1997), Weltman et al. (1986), and Santos and Janeira (2012) show improved vertical jump ability as a result of strength training interventions, whereas Faigenbaum et al. 1993, Faigenbaum et al. 1996, Faigenbaum et al. (2002), Faigenbaum et al. (2005), and Lillegard et al. 1997 showed non-significant results. An additional study by Faigenbaum et al. (2007) showed a non-significant increase in vertical jump due to Resistance Training (RT) only, compared to a combined RT and plyometric group. This study did not involve a control group, so it is not certain whether there would have been a true significant difference.

The inconsistent results in child RT/VJ studies are likely due to the length of training interventions, number of sets, vertical jump testing methods, number of participants, gender of participants, randomization of group assignment, and the use of blinded observers. A meta-analysis by Payne et al. (1997) determined that effect size and treatment duration were related in resistance training studies using pre- and post-test design with an effect size of 0.22. However this meta-analysis examined studies looking at gains in muscular strength and endurance. It might not be appropriate to apply these findings to gains in motor performance like vertical jump. However, studies showing a significant difference used at least 10 weeks of training. Santos and Janeira (2012) used a 10-week intervention, Hetzler et al (1997) used a 12-week intervention, Weltman et al. (1986) used a 14-week intervention, and Christou et al used a 16-week intervention. Most of the studies that did not show a significant difference, Faigenbaum et al. (1993), Faigenbaum et al. (1996), Faigenbaum (2002), Faigenbaum et al. (2005) and

Faigenbaum et al. (2007), each used intervention lengths of eight weeks, eight weeks, eight weeks, eight weeks and six weeks respectively. The only exception was Lillegard et al (1997), which used a 12-week intervention. More research is needed in order to clarify the relationship between intervention duration and gains in motor performance in this population.

The number of sets, which help determine volume, can affect how well an intervention works (Ratamess et al. 2009). Volume is one of the key fitness principles along with intensity, frequency, time and type of exercise (Ratamess et al. 2009). All the studies that demonstrated a significant difference used multiple sets (two to three), on at least their primary exercises. Faigenbaum (2002), Faigenbaum et al. (2005), which did not show significant differences, used a single set repetition scheme. Faigenbaum et al. (2007) had an increased volume, using one to three sets, while Faigenbaum et al. (1996) used two to three sets. Lillegard et al. (1997) used three sets. Unfortunately Faigenbaum et al. (1996), Faigenbaum et al. (2007) and Lillegard et al. (1997), did not show significant differences between groups. It appears that in most cases, multiple sets and multiple day per week interventions of longer lengths seem to lead to better vertical jump outcomes compared to control groups. The short interventions with single sets might not provide a proper stimulus for change. However, long interventions are not always possible for practical reasons.

The testing method can affect the effectiveness of an intervention due to varying reliability (Klavora 2000). Some tests might hold up under certain situations better than others (i.e., different populations or different outcome variables). The studies that showed non-significant differences in vertical jump height between experimental and control groups used the jump and reach style tests (Faigenbaum et al. 1993; Faigenbaum et al. 1996; Faigenbaum 2002; Faigenbaum et al. 2005; Lillegard et al 1997). However, there was a study that used a jump and reach style test that did demonstrate a significant difference (Hetzler et al. 1997). Weltman et al. (1986) used a jump and reach style test and showed significant main effects and a significant interaction effect in the experimental group compared to the control group.

The number of participants was another source of variability. Faigenbaum (2002) involved 55 participants, Faigenbaum (2005) involved 43 participants and Lillegard et al. (1997) involved 91 participants, all of which involved more participants than any study involving a difference in outcomes. The increased number of participants could mean higher statistical power; less sampling error and more importantly, a bigger chance of realizing the effect if in fact there is an effect.

Since the current study involved only females it was desirable to find studies involving just females. Unfortunately studies of only females were not found. All studies found involved just males or a combination of males and females. Results from studies involving females and males might not be as appropriate as studies involving only females. Four of five studies showing non-significant differences involved males and females, whereas only one study showing significant differences involved males and females. It appears that with a homogenous group it is easier to detect changes, or males are more likely to improve as compared to females.

Randomization of allocations to training groups can help decrease bias in order to detect actual changes. Interestingly, the studies that did not show a significant difference between groups were all randomized (Faigenbaum et al. 1993; Faigenbaum et al 2002; Faigenbaum et al. 2005; Faigenbaum et al. 2007, and Lillegard et al. 1997) except for one, Faigenbaum et al. (1996). From the studies that showed a significant difference between groups, only Santos and Janeira (2012) was randomized. Christou et al. (2006), Hetzler et al. (1997), and Weltman et al. (1986) were not randomized.

Having blinded observers/assessors can help to decrease bias (Pannucci and Wilkins 2010), in order to detect actual changes. None of the studies examined stated that blinded assessors were used, leading to the assumption that they were not used.

Table 1. Strength training in relation to VJ in children (Significant difference)

Study	Design of study	Type of Training/Length of Training	Measurements	Findings
Hetzler et al. 1997	-30 12-15 year old males, 3 groups of 10, no RT experience -NTG, ETG, CON -Non blinded, non-randomized -During baseball preseason	-3x10 at 50,75,100% of 10RM, 12 weeks 3x/week, circuit style -On free weights and machines (all leg exercises on machines) 2 instructors for all 30	- CMJ: Jump and reach test using wall, in bare feet (best of 3 trials) -FamS same day	-Significant increase in VJ for NTG and ETG (smaller) compared to control -CON showed no change -No injuries
Christou et al. 2006	-18 male soccer players w/ RT experience 12 to 15 years old: STR (n= 9) and SOC (n=9), CON group (n=8) -Non blinded -Non randomized -During soccer in-season	-4 weeks of 2x15 FamS -2 x / week, 16 weeks of 55%-80% 1RM, 2–3 sets of 8–15 reps -One instructor for team - Soccer 5x/week, 90min + 70 min game. FW + machines (all leg exercises on machines)	-SJ, CMJ, RJ on contact mat (best of 3 trials), hands on waist -2 to 3 FamS -Test at baseline, 8 weeks, 16 weeks	-Significant increase in SJ for STR (7.5 cm increase), non-significant increase for SOC (2.1 cm increase) and CON (2cm increase) groups -Significant increase in CMJ for STR (6.7cm increase), non-significant increase for SOC (1.4cm increase) and CON (2.2cm increase) groups -No injuries

Weltman et al. 1986	-29 males, 6-11 years,19 in EXP group (3 DNF), 10 in CON group -Non blinded, non randomized -Participants active in 1-2 sports	-3x/week, 14 weeks, circuits -3x30s (AMAP) 30s rest for 10 stations -On hydraulic machines -No supervision details	-CMJ: Jump and reach using wall (mean of 3 trials) -3 to 5 Familiarization jumps	-VJ improved more in EXP (2.2cm increase) than CON (0.7cm decrease) with a significant main effect and significant two way interaction -No injuries
Santos and Janeira 2012	25 males EXP (n=15), CON (n=10) 13-15 years -No RT experience -Randomized -Non blinded	-10 weeks, 2x/week. 2x10-12(week 1-2), 3x10-12(week 3-10)(10RM) + soccer training. -On Nautilus machines except 2 exercises -3 instructors for all participants	-SJ, CMJ with and without arms on contact platform (Mean of 3 trials) -Hands on hips -FamS	-Significant improvements in SJ (3.11cm increase) compared to CON (1.96 cm decrease) -Significant increase in CMJ (3.38cm increase) compared to CON (2.36cm decrease) -Significant increase in CMJ with arms (3.89cm increase) compared to CON (1.8 cm decrease) -No injuries reported

RM=Repetition maximum; CON=control group; VJ=vertical jump; RT=resistance training; CMJ=countermovement jump; SJ=squat jump; RJ=reactive jump; EXP=experimental group; SLJ=standing long jump; LP=leg press; BP=Bench press; CP=chest press; STR=strength group; SOC=soccer group; HIIT=high intensity interval training; U=under; UB=upper body; LB=lower body; SG=supervised group; VG=video group; LRM=low repetition maximum group; HRM=high repetition maximum group; TTG=twice per week training group; OTG= once per week training group; MBT=medicine ball throw; NTG=novice training group; ETG=experienced training group; DNF=did not finish; FamS=Familiarization session; FW=free weights

Table 2: Strength training in relation to VJ in children (Non-significant difference)

Study	Design of study	Type of Training/Length of Training	Measurements	Findings
Faigenbaum et al. 1993	-25 males and females 8-12 years old. EXP (n=15, 11 males and 4 females) CON (n=10, 6 males and 4 females) mean age of 9.9 -Randomized -Non blinded -Most kids participated in sports	-8 weeks, 2x/week. 3x 10-15 reps (50%, 75% 100% 10RM) for 5 primary exercises, then 1-3 sets of 15 on secondary exercises -On cable machines Instructor to participant ratio of 1:5	-Jump and reach using wall (best of 3 trials),1 week FamS	-Significant main effect for VJ for EXP (3.14cm increase) vs. CON (1.49cm increase) with non-significant two way interaction -No injuries
Faigenbaum et al. 1996	-14 males, 10 females 7-12 years old, no RT experience EXP: 11 males, 4 females, CON: 3 males, 6 females -Non blinded, non-randomized -Participants participated in sports	-2x per week, 8 weeks -Training first 4 weeks; 1x10 sub max, 2x6 max (primary + secondary exercises) (6RM load). Last 4 weeks: 3x6 primary, 2x6 secondary. 7 exercises -Child size machines Instructor to participant ratio of 1:4	-VJ: Jump and reach using wall (best of 3 trials) Tested before and after training period plus midway and after detraining period,1 week FamS	-Non significant increase in VJ height -Significant main effects for time

Faigenbaum et al. 2002	-21 females, 34 males aged 7.1 to 12.3 no RT experience TTG (2x/week, n=20, 9 females and 11 males) OTG (1x/week, n=22, 7 females and 15 males), (CON, n=13, 5 females and 8 males) -Non blinded, non-randomized, -Activity level not stated	-1x or 2x per week, 8 weeks -1x10-15 reps, 12 exercises (2 core, 10 RT) (60-70% 1RM) -On child size machines -Instructor to participant ratio of 1:3	-CMJ: Jump and reach on wall (best of 3 trials) -1 FamS	-Non significant gains in VJ for OTG (1.2cm increase) and TTG (2.1cm increase) compared to CON (0.7cm increase) -No injuries
Faigenbaum et al. 2005	-23 females and 20 males 8.0 +12.3,no RT experience LRM (6 females, 6 males), HRM group (8 females, 11 males), CON group (9 females, 3 males) -Randomized between LRM and HRM -Non blinded ,most played sports	-1 set 2x/week for 8 weeks, 9 machine exercises + core -6 to 10 reps for LRM (6-10RM) -15-20 reps for HRM group (15-20RM) -On child size plate loaded machines -Instructor to participant ratio of 1:3	-Jump and reach test on wall (Best of 3 trials), 2 FamS	-Non significant gains in VJ for LRM (0.8cm increase) and HRM (not available) compared to CON (0.6cm increase), No injuries

Faigenbaum et al. 2007	-27 males 12-15yrs -RTG (n=14) or PRTG (n=13), no CON -RT experience -Randomized -Non blinded, Mostly baseball and football participation	-2x/week, 6 weeks -RTG: Cleans, snatches with dowel or empty bar (1-3 sets of 4 reps) -3x10-12 reps (loads not prescribed) (Including squats and front squats) -Mostly FW ,1:4 supervisor to participant ratio	-CMJ using Vertec (best of 2 trials), 1 FamS	-RTG showed non-significant increase in VJ (1.4cm increase), no CON -No injuries
Lillegard et al. 1997	-91 males and females aged 9-13 -Prepubescent EXP (20 males, 8 females) Prepubescent CON (18 males, 6 females) -Early postpubescent EXP (16 males, 8 females) -Early postpubescent CON (10 males, 5 females) Randomized, Participated in sports	12 weeks, 3x/week -3x10 reps of 10RM, FW and machines (leg exercises on machines), 1:4 supervisor to participant ratio	CMJ: Jump and Reach test on wall (best of 3 trials), no FamS, but explained and demonstrated	-No significant increases in VJ, in fact some group means decreased -Treatment (not gender or tanner stage) was biggest main effect -Treatment and gender: largest interaction -One injury (shoulder)

RM=Repetition maximum; CON=control group; VJ=vertical jump; RT=resistance training; CMJ=countermovement jump; SJ=squat jump; RJ=reactive jump; EXP=experimental group; SLJ=standing long jump; LP=leg press; BP=Bench press; CP=chest press;

STR=strength group; SOC=soccer group; HIIT=high intensity interval training; U=under; UB=upper body; LB=lower body; SG=supervised group; VG=video group; LRM=low repetition maximum group; HRM=high repetition maximum group; TTG=twice per week training group; OTG= once per week training group; MBT=medicine ball throw; NTG=novice training group; ETG=experienced training group; DNF=did not finish; FamS=Familiarization session; FW=free weights

Studies involving longer training interventions, multiple days of training per week as well as multiple sets seem to allow for a larger stimulus of change. When examining the number of participants in the various studies, there appears to be a greater number of participants in the studies that did not show a significant difference. This is an unusual result since a larger sample usually allows for easier detection of a significant difference (Hopkins 2007), if in fact there is one. Another unusual result was finding studies using the jump and reach method that showed significant differences as well as non-significant differences. It appears that the number of participants and the testing method are less important than the volume and frequency of training. It appears that with a homogenous group (gender) it is easier to detect changes, as most studies showing significant change involved males only. Studies involving females only are needed in order to generalize strength training study findings to females more appropriately. An additional note is the mode of exercise performed in these training studies. Every single study except one (Faigenbaum et al. 2007) used resistance machines and not free weights to train the participants' legs. However, Faigenbaum et al. (2007), which used free weights did not show significant differences. There were a few studies that used free weights for the upper body (Hetzler et al. 1997; Christou et al. 2006; Lillegard et al. 1997), but upper body weights are not specific enough to increase strength for vertical jump height.

2.4 Overall Aim or Purpose of Study

The purpose of this study was to determine if a 12-week, two-time per week, multiple set strength training intervention for the lower body, using free weights only, would produce a change in vertical jump performance in athletic female children aged 10-14 years old, above and beyond normal growth and development as demonstrated by a control group.

2.5 Hypothesis

The hypothesis of this study is that the experimental group involved in lower body strength training will increase their vertical jump scores more than a control group doing upper body strength training. It is believed that strengthening the leg muscles, using an appropriate intervention period, with adequate volume and frequency of training, as well a simple test will favor a detection of significant change in the experimental (lower body) group. It is believed that increasing leg muscle strength will provide a large enough contribution to a vertical jump without the use of arms, to produce a significant difference compared to a control group.

3. Methods

3.1 Introduction

The present study was part of a larger study led by Joanne Parsons, seeking to determine if there is an effect of resistance training on jump landing biomechanics and hence risk factors for ACL injuries. All testing procedures are described below, however not all of them are directly relevant for this thesis.

3.2 Study Design

The proposed study was a randomized controlled trial with a blinded observer (for baseline and post-tests). It involved two testing periods, a baseline test completed before the intervention and a post-test completed after the intervention. The tests of the larger study and the tests of the present study were conducted in the same session. The baseline test and post-test were conducted by a trained research assistant without him knowing the group assignment. Once baseline testing was completed, the participants were randomly assigned to one of two training groups. One group was the experimental group, who participated in lower body training. The other was the control group who participated in upper body training. Random assignment happened by way of a sealed envelope handed to the participant containing their group assignment**.** The trainers were also blinded to the results of the testing until the completion of the study.

3.3 Participants

The proposed study involved girls aged 10-14 years old. All the participants were athletic, playing sports involving jumping, cutting, and running.

3.3.1 Recruitment

Upon receiving permission from the ethics committee, posters were put up around the University of Manitoba and local community centres. In addition, emails were sent to club and provincial sporting organizations. Interested participants and a parent/guardian contacted the principal researcher for a three-way phone interview. During the phone interview, a script was followed that explained the study in detail, obtained baseline information (e.g., name, date of birth) and also asked eligibility questions. Essentially, the phone interview served as a screening protocol. The inclusion criteria were: girls between the age of 10-14 at time of baseline testing, and participation in sports with jumping, running and cutting, pivoting (e.g., basketball, soccer, football) for a minimum of one year. The specific amount of participation within each year was not controlled. The exclusion criteria were: participation in organized resistance training or formal jump training in the last six months, and presence of an injury or condition that would affect the participant's ability to exercise safely. If deemed eligible to participate, consent and assent forms as well as information packages were emailed to guardians and participants to read over. During the phone interview there was a separate set of questions that involved collecting information on maturation/physical development, sport history, and leg dominance. Leg dominance was determined by asking with which leg they would use to kick a ball (Hewett, Myer and Ford 2004). The information package also contained directions to the testing and training rooms and information on the principal and secondary researchers' qualifications.

Maturational status was determined by the researcher, parent, and child via the Pubertal Maturation Observational Scale (Davies and Rose 1999) also known as PMOS.

3.4 Baseline testing

After the participant and their parent/guardian signed the assent and consent forms, the testing procedures as well as possible risks were explained to the athlete and parent.

Height was measured to the nearest 0.5 cm using a Tanita Stadiometer (Tanita Corporation of America, Inc., Arlington Heights, Illinois), without any shoes. Body mass was measured to the nearest 0.5 kg on the Health-o-meter (Pelstar LLC, Alsip, Illinois) professional upright scale.

Warm-up consisted of a continuous treadmill walk for five minutes. The speed was increased gradually from 0 km/h to approximately 3 km/h. The athletes were instructed to hold on to the handrails for the duration of the treadmill walk.

The Landing Error Scoring System Real Time (LESS-RT) (Pauda et al. 2009) was used by the tester in order to rate the jump landing ability of the participants. The LESS-RT involved a series of qualifying points, all with a scoring scale. The participant was instructed to jump off a 30 cm box to a tape target on the floor. Two video cameras, placed at the sagittal view and frontal view, were used in order to capture the jump landing.

The pushup test of upper body strength/endurance required the participants to complete the maximum number of pushups possible consecutively with proper technique. The test had the athlete start in the prone position on the floor. She then proceeded to push up from the prone position to full elbow lockout then down to 90° of elbow flexion. The test was stopped when the athlete could no longer complete any reps or proper form was not maintained over two consecutive repetitions.

The athlete's grip strength was tested using a Jamar Hand Dynamometer (Sammons Preston, Bollingbrook, IL, USA). The athlete sat in a chair or on a box with their elbow bent at 90° at the side of the body. Three trials per hand were given in an alternating fashion, starting with the right hand. The mean of the three trials per hand were used for analysis.

Leg strength and power were assessed using a Biodex Isokinetic Dynamometer (Biodex Medical Systems, Shirley, NY). The hip and knee joints were tested under constant muscle length conditions (three maximal trials), dynamic muscle length conditions (five maximal trials) and constant velocity conditions (five maximal trials). The Biodex Isokinetic Dynamometer measurements were part of the larger study and not part of the present study, thus further explanation is not warranted.

Vertical jump ability was assessed using the University of Toronto Belt Jump (Sport Books Publisher, Toronto, ON). To use this device, the athlete took the black strap attached to the yellow tape measure (proximal end) and fastened it around the waist. Once the belt was secure, the athlete stood on the blue feet markings located on the gray mat where the tape measure is set to zero. From an upright position, the athlete performed a countermovement then jumped straight up as high as possible trying to land back on the foot markings. The height jumped was the number indicated on the tape. The University of Toronto Belt Jump is an improved version of the Abalabov Belt Jump device due the removal of a potentially hazardous metal apparatus and the addition of a soft landing mat. The best of three trials of a countermovement jump with and without arms was used for analysis. No familiarization jumps were given due to the simplicity of the task as well as to minimize fatigue.

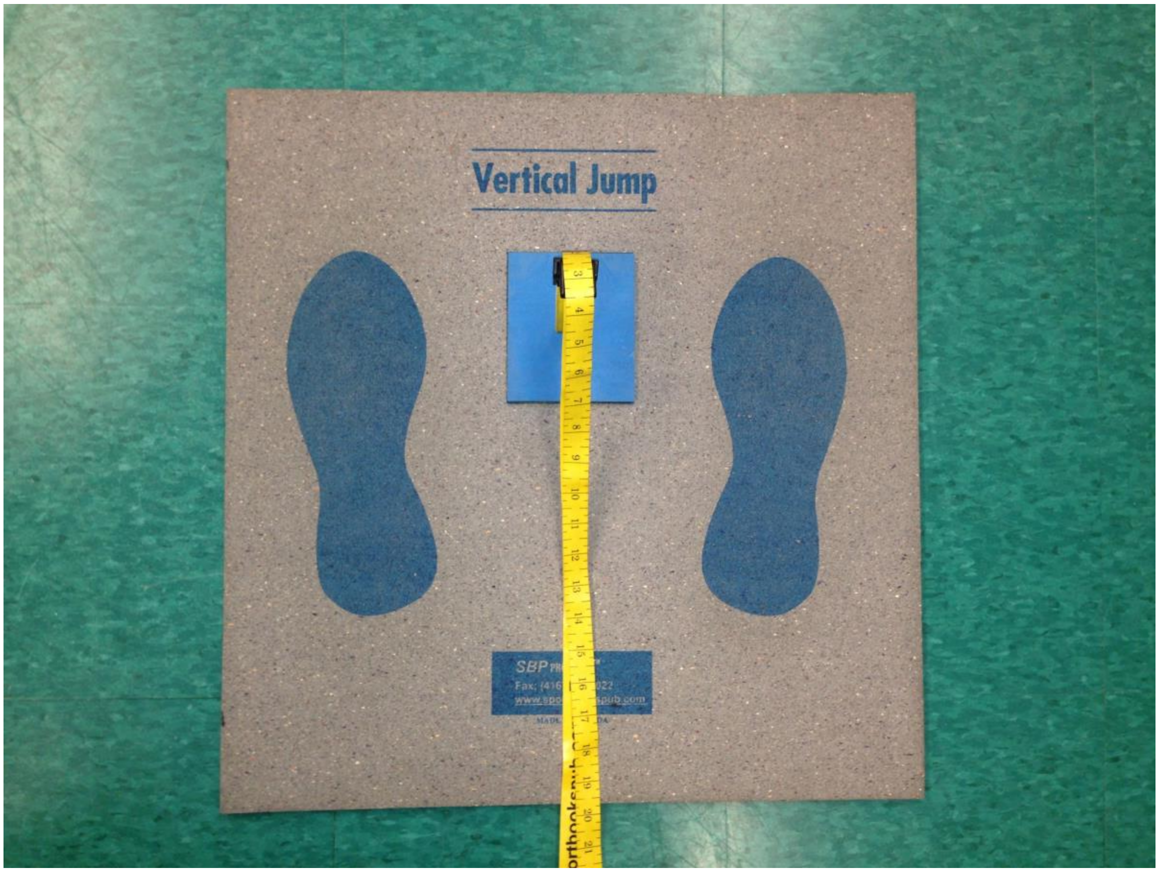

Figure 2. University of Toronto Belt Jump (Sport Books Publisher, Toronto, ON)

3.5 Training Protocols

The lead researcher conducted training along with an assistant, both were certified and qualified to conduct exercise sessions. Training sessions started with about five to seven minutes of warm up which included: jogging, shuffling, grapevine, butt kicks and high knee skips. Both the lower body and upper body training groups performed these same movement drills but differed in their mobility drills. The lower body group performed forward/backwards leg swings (Figure 3), Spiderman stretches, (Figure 4) and ten body weight squats (Figure 5). The upper body group performed ten arm circles forwards and backwards, ten thoracic rotations from a quadruped position (Figure 6), and ten wall angels (sliding arm up and down the wall with 90 degree shoulder and elbow bend, Figure 7). Training sessions lasted approximately one hour where the researcher coached proper form and progression.

Figure 3. Forwards, backwards leg swings

Figure 4. Spiderman stretch

Figure 5. Body weight squats

Figure 6. Quadruped thoracic rotations

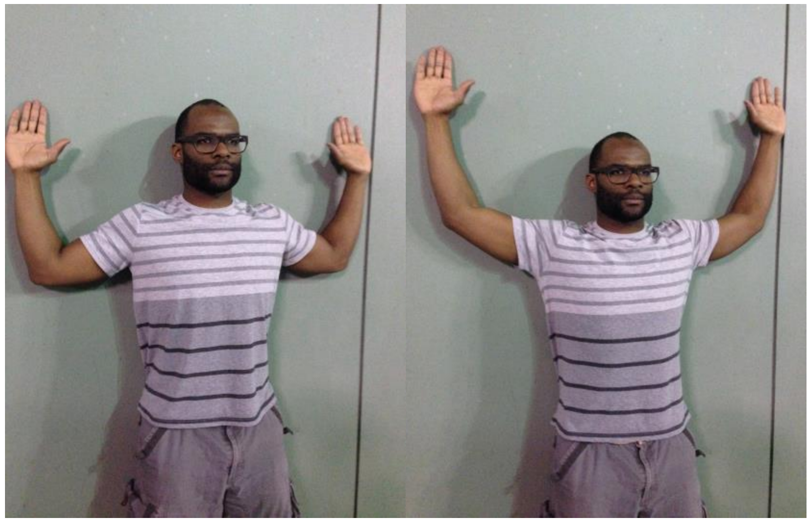

Figure 7. Wall angels

The following four exercises were used for the lower body training group: free weight squats using dumbbells and barbells, dumbbell free weight lunges, side lying hip abduction with ankle weights and three possible variations of a supine leg curl exercise. Free weights were used due to facility limitations, cost limitations, and the similarity of free weight exercises to movement tasks (Ratamess et al. 2009). The velocity with which all lifts were performed was a slow controlled velocity approximately equal to two seconds on the way down (eccentric portion) and two seconds on the way up (concentric portion). Although velocity of movement can affect training (Faigenbaum et al. 2009), this self-selected slow controlled velocity was deemed best in order to reduce confusion for the athlete and maximize task learning.

To perform the free weight squat, participants were asked to assume a stance with feet set approximately shoulder width apart, with their trunk held as tall as possible. Participants were then instructed to receive the bar on their trapezius and shoulder muscles and hold tight with their hands. Participants were then instructed to sit in an imaginary chair behind them where the researcher would visually observe the depth reached by the superior portion of the hamstrings. The desired depth was 90°, which all participants attempted to achieve except in special circumstances like joint soreness. After reaching the required depth the participants would then stand up and repeat the action. Adaptations that were used in cases of inefficiencies in squat technique were using a bench as a target for the participant to squat down to, as well as using a wider stance. Dumbbell goblet squats were used in some cases to aid with squat form before returning to barbell squats.

To perform the free weight lunges, participants were asked to pick up one dumbbell per hand, place the feet together then take a large step forward. Afterwards, they lowered their body towards the ground by flexing the hip and knee of the back leg until the lower leg became parallel with the ground at the bottom. After reaching the bottom the body was raised upwards by extending the hip and knee. For the dumbbell lunges, problems that arose were balance and grip issues. For balance issues, the participant was asked to stare at one single point on the wall and "grip the ground with their toes" inside their shoe. For grip issues, they were allowed to place the weights down momentarily in between sides (i.e., 10s rest after completing left leg and before completing right leg).

For leg abduction, participants were instructed to lie on their side with their legs stacked one on top of the other. They were then instructed to raise their top leg to approximately a 45° angle, and then return it towards the ground in a controlled manner. Participants were progressed from no ankle weight load to ankle weight loads that were challenging but still allowed for proper technique. In cases of strong participants, two ankle weights were used per leg. The only technique issue that came up was when the participant bent their knee too much, in which case they were instructed to straighten it.

The leg curl exercise required participants to lay supine with the bottom of the feet perpendicular to the ground and buttocks off the ground. The participants then flexed both knees simultaneously in order to pull the feet towards the buttocks. This action produced tension in the hamstring muscles. Three different variations of the leg curl exercise were used. The first variation of leg curls used a towel in which the participant slid on the floor. This first variation was meant as an introductory exercise. The next step was a stability ball leg curl in order to challenge their balance. The third variation was the towel leg curl with ankle weights, in which loads could be added. These three variations served as a fun exercise for the participants to look forward to as well to challenge the strength of the hamstrings and balance of the body.

The following exercises were used for the upper body training group; dumbbell lying chest press, dumbbell biceps curl, standing or seated dumbbell overhead press, and bent over dumbbell rows. For the chest press, the athletes were instructed to lay supine on the bench, weights in hands with elbows flexed at 90° and shoulders abducted to 90°. The athletes were then instructed to push the dumbbells upwards until the arms reached a fully extended position, at which point the load was returned to the starting position. For the bicep curls, the athletes would stand tall with dumbbells in hand by their sides and arms extended. They would then fully flex their elbows then return back to start position. The overhead press required the athletes to hold the weight beside their head with shoulders and elbows flexed to 90°. The weight was then pushed overhead and returned back to the start position. The dumbbell row involved the athletes being in a quadruped position on the bench. With the dumbbell in one hand, they would pull up and back up to approximately the hip and then return back to the start position.

In cases where the chest press gave difficulty, a possible adjustment was to shorten the range of motion to 90°, so the arms did not sink as deep past the chest. For the biceps curls and dumbbell overhead press, standing against the wall provided stability to the movement, which helped in completion of the lift. In a case where the press gave trouble, an alternative exercise like the triceps kickback, was selected. The last exercise, dumbbell rows usually needed cueing for proper trunk position, because it was sometimes difficult to maintain a neutral spine. Adjustments made were a stick placed on the athlete's back to help with positioning or a mat placed under the hand, to help maintain a neutral spine (for long armed people).

Familiarization sessions were conducted for the first three visits where the researcher coached the participants in the specified exercises. The purpose of the familiarization sessions was to ensure that the strength testing revealed more about actual gains in strength and less about increased coordination (Naughton et al. 2000). During these familiarization sessions, the participant attempted the first few sets by lifting an arbitrary and relatively low load 10-15 times, and continued to progress from there.

On the fourth visit, a 10 RM strength test was completed. This test represented the maximum amount of resistance that the participant could successfully lift ten times with proper technique. In the experimental group, 10 RM tests were completed for squats and lunges. In the upper-body training group, 10 RM tests were completed for bench press and biceps curls. According to Hetzler et al. (1997), 10 RM tests are safe in the presence of qualified instruction and appropriate supervision. The test started with an arbitrary load completed approximately 10-15 times. A three minute rest was given between sets to allow proper recovery. Loading increases thereafter were around two and a half to ten percent increases. The test was stopped when the participant could no longer lift the respective load 10 times with adequate technique.

The 10RM tests were not used as an outcome variable because the procedure did not use a blinded observer, and the groups did not perform both upper and lower body tests. Results from the 10RM testing were used to determine appropriate loads specific to each participant.

During training, for the free weight squat and lunges, three sets were attempted by the participant. Set one used a load of 50% 10RM, the second set used a load of 70% 10RM and the third set used a 100% 10RM load (Faigenbaum et al.1993, Hetzler et al. 1997). The same loading protocol was used for the control group except it was used for the free weight chest press and the free weight biceps curl. Researchers instructed participants to complete the exercise using a controlled tempo during the eccentric and concentric portions of the lift, to maximize safety and technique.

Loads were progressed between five and ten percent once the participant was able to complete 15 repetitions with proper technique using the 10RM load (Faigenbaum et al. 2002). Researcher observational skills and a rating of perceived exertion were used to determine the appropriate times to increase the load. The OMNI resistance exercise scale (Robertson et al. 2005) was used to ask the participants how difficult they perceived the load to be. It is based on a scale of zero to ten with zero being extremely easy and ten being extremely hard. Only two sets were completed for the last two exercises in both groups. Throughout the training intervention, one minute of rest was given between sets of the same exercises whereas three minutes were given between different exercises.

Additional variables recorded were the athlete's perceived soreness as well as their athletic participation record. At the beginning of the session the athletes were asked if they were sore from the previous workout. If yes, they were then asked how sore on scale of one to ten. Considerations taken for a yes answer were volume and intensity decreases, which were marked appropriately. Those same changes and possibly more were also made if the athlete reported an injury (asked by the researcher) or pain somewhere on the body. If the athlete happened to sustain an injury outside of the study, it was recorded on the exercise-recording sheet. The participation record included the total minutes of participation in organized sports per week. Only participation in organized sports and physical activity was recorded (i.e., basketball practice, soccer game etc.), whereas non-structured physical activity (going for a jog) was not recorded. These recordings were used to help explain findings.

Of further note, it is known that the velocity of a muscle contraction during training has an influence on the body's response to training in order to increase vertical jump (Meylan and Malatesta 2009). The plan was for the participants of this study to complete exercises utilizing faster movement velocities caused by faster muscle contractions at around week nine of the intervention. However in the interest of safety, it was deemed necessary to abandon that idea. It was determined that the technique of the participants performing the free weight squats would most likely breakdown if they were to perform them faster.

3.6 Post testing

Identical procedures were performed on post-test day as baseline day. The athlete was given a piece of paper to sign, asking if they would like to be contacted for future studies. The blinded assessor was not aware of the baseline results for any variable.

3.7 Statistical analysis

A variety of different statistical packages were used in the analysis of the data for this project: SPSS (SPSS Inc., Chicago, Illinois), G-Power (Faul, Erdfelder, Lang, & Buchner, 2007), Microsoft Excel, (Microsoft Corporation, Redmond, Washington, 2007), and SigmaPlot (Systat Software Inc., San Jose, CA).

The primary outcome variable in this study was the countermovement jump without the use of arms. This study was concerned with the effectiveness of the treatment and not the maximization of vertical jump for other purposes (i.e., sports). Therefore the vertical jump without the use of arms was a better choice as the primary outcome variable, since the training of interest was directed at the lower body. Other variables examined included: the countermovement jump with the use of arms, right and left grip strength, Biodex Isokinetic Dynamometer measurements, and a pushup test. Grip strength and pushups were analyzed to determine the effectiveness of the control group's treatment.

To assess differences in the means between the groups over time, two way repeated measures ANOVAs were used. This type of test allows for assessment of differences within and between groups. Due to the presence of the control group and the measurement that was repeated after a certain time period, a two way repeated measures ANOVA (group and time) was warranted. Treatment served as the independent variable and vertical jump height as the dependent variable, while time served as the repeated measure. An analysis of the interaction of group and treatment was also done (Hopkins 2012. Two way repeated measures ANOVAs were also completed for countermovement jump with arms, pushups, and left and right grip strength measurements. Other statistical measures completed were descriptive statistics and Independent samples T-tests of participant baseline characteristics, pushups, and left and right grip strength, in order to determine if the groups were significantly different at baseline. Pubertal maturation score frequency was calculated in order to determine the breakdown of prepubertal, pubertal and postpubertal participants in the study. Descriptive statistics and independent samples T-test were also completed for the number of workouts attended and number of activity minutes completed.

3.7.1 Sample Size

A sample size of 34 was determined to be suitable for the primary outcome of interest for the larger study. It was based on statistical calculations specific for the jump-landing test. For the present study, based on an A priori analysis in G Power (Faul et al. 2009), sample size estimation was calculated by estimation of an expected effect size of 0.49, a desired statistical power of 0.8 and user specified alpha of 0.05. According to the analysis, the appropriate sample size was 12 participants per group. Since the present study had 36 participants with 19 in the lower body group and 17 in the upper body group, there should have been sufficient power. An effect size of 0.49 or moderate was used in the calculation of sample size based on the reported effect size of the same by Christou et al. (2006). After examination of studies showing significant differences in vertical jump height, a mean change in vertical jump of 3.9 ± 4.5 cm was revealed. The minimum absolute change of 2.2 ± 3.4 cm seen came from Weltman et al. (1986) and the largest of 6.9 ± 0.8 cm came from Christou et al. (2006).

4. Results

4.1 Participants

The present study involved athletic females aged 10-14 years old at the time of baseline testing. Forty-seven females in total were assessed for eligibility, out of which seven were excluded. Out of those seven participants, five did not meet the inclusion criteria and two declined to participate. Forty females were then randomized, in which 20 were allocated to the lower body experimental group and 20 were allocated to the upper body control group. Randomization occurred in blocks of four, where two participants were assigned to each group for every four participants recruited. Participants were notified of their group assignment using a sealed envelope. The assessor was unaware of their group assignment. In total, four participants withdrew from the study. One participant withdrew from the experimental group due to lack of interest. Three participants withdrew from the control group, two for lack of time and one due to an injury that happened outside of the study. Thirty-six participants were analyzed in total, 19 in the experimental group and 17 in the control group (refer to Figure 8). There was also a participant who did not complete the vertical jump portion of the post-test battery due to a tester error. Furthermore, there was one participant who did not complete the grip strength or pushup tests due to a family trip.

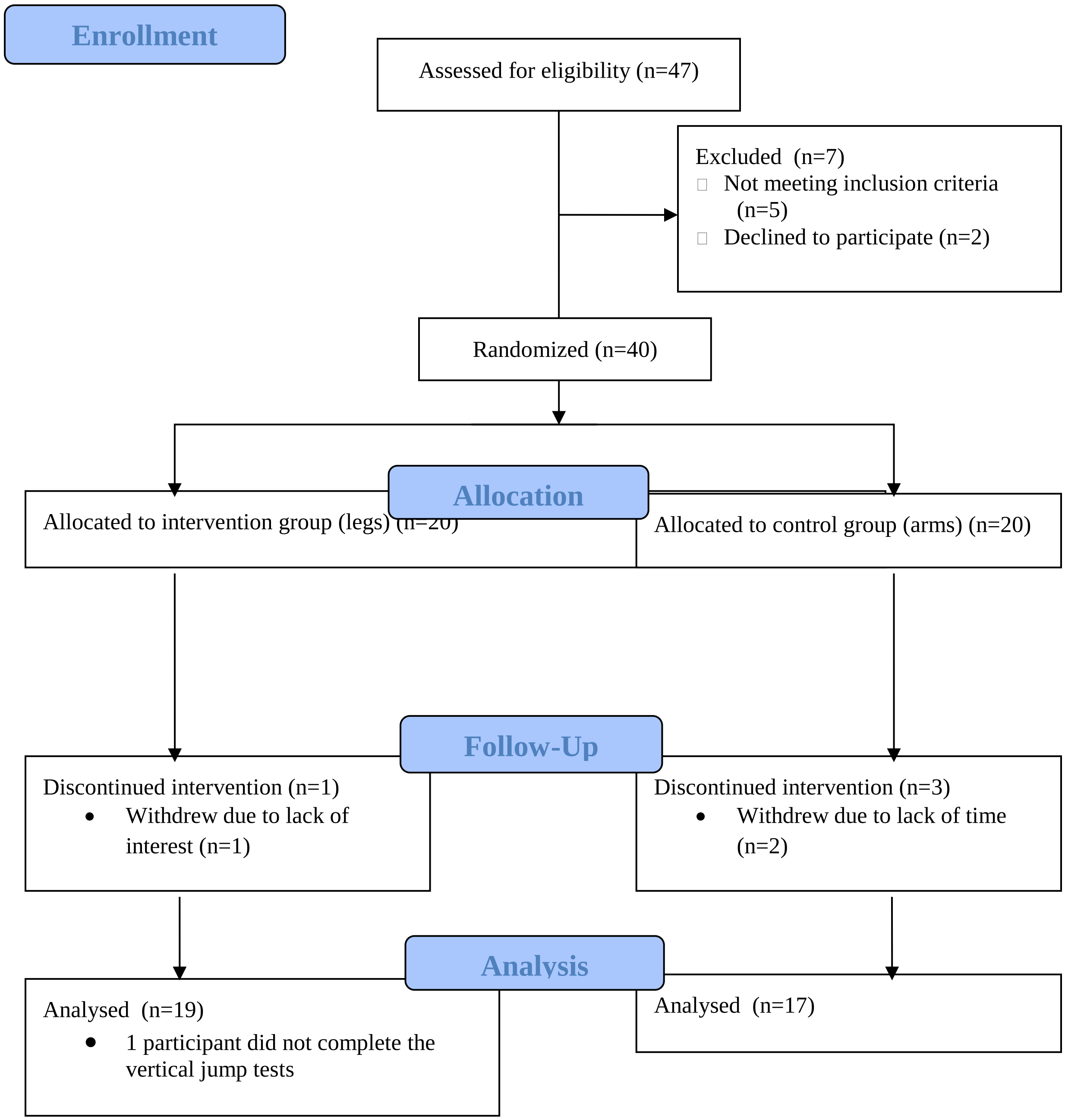

Figure 8. Participant recruitment flow diagram

There were no injuries that occurred during study testing or training, but there were a few injuries outside the study while the participants played their respective sports. Two participants experienced injured ankles playing sports. Neither participant missed any training but one experienced difficulty with the post-test. Her ability to perform to the best of her ability was compromised but nonetheless she completed all post-testing procedures. Another participant fractured a bone in her left forearm during school activities near the end of the intervention period. She did not complete the left grip procedure but did complete the jumps without any problems. Another participant injured her neck playing baseball and had to take two weeks off from training before returning. She completed all post testing. Another athlete experienced day-to-day soreness in the knee due to excessive soccer. She did not perform the lunges and instead was given step ups because step-ups did not irritate her knee. She performed all post-testing except for the Biodex procedures due to its malfunction. Other day-to-day ailments came up, but did not cause the participants to miss any training sessions. Furthermore, the exercises were adjusted in the case of day-to-day ailments.

The number of sessions attended on average was 19.8 for an attendance rate of 82.5%. Of note, there were only three participants that completed the entire 24 sessions and another 15 that completed 20 or more.

Participant baseline characteristics are listed in Table 3. The mean age values for the lower body group was 4559.4 ± 514.9 days (12.5 ± 1.4 years), and 4373.4 ± 485.3 days (11.9 ± 1.3 years) for the upper body group. The difference between ages for the groups was not statistically different (P=0.3). Other baseline characteristics recorded were body mass, body height, the age the participant began organized sport, the number of years of participation in that sport, as well as a pubertal maturation score (PMOS). The PMOS is based on a scale of one to eight points indicating the child's level of maturation. A score of one or less indicated pre-puberty, a score of four to five indicates puberty, and a score of at least six indicates post-puberty. Values of 3 or less represented 25% of the participants whereas a value of one was represented by only 2.8% (pre-puberty). A score of four to five represented 22.2%, while a score of at least six represented the remaining 52.8%. Pubertal maturation score did not differ significantly at baseline (*P*=0.8). Values for body mass (*P*=0.9), body height (*P*=0.9) and age began organized sport (*P*=0.15) did not differ significantly at baseline. Only the number of years of participation in sports displayed a significant difference at baseline (*P*=0.04), with the lower body group having a higher mean of 7.6 ± 2.03 years versus 6.1 ± 2.1 years.

Table 3. Participant baseline characteristics

Table 3: Participant baseline characteristics	Lower Body M/SD (n=19)	Upper body M/SD (n=17)	*P*-Value
Age (days)	4559.4 ± 514.9	4373.4 ± 485.3	0.27
Height (cm)	156.9 ± 11.6	156.4 ± 10.6	0.89
Mass (kg)	50.8 ± 15.7	51.5 ± 12.2	0.88
Age began organized sport	4.5 ± 1.3	5.5 ± 2.5	0.15
Number of years in sport	7.6 ± 2	6.1 ± 2.1	0.04*
Pubertal Maturation score	5.21 ± 2.2	5.3 ± 2.2	0.85

*Significant difference between groups

4.2 Countermovement Jump No arms

The primary outcome measure of this study was a countermovement jump without the use of arms in which the best jump of three was used in the analysis. There were no significant differences at baseline displayed between the two groups. Table 4 displays the results of both groups for the mean values for both jump types as well as pushups and grip strength and figures 9 and 10 show graphs of baseline and post-test scores of each group. There was no significant main effect for time (*P*=0.8), as well as no main effect for group (*P*=0.8). In addition, there was no significant interaction (*P*=0.9).

Table 4: Mean (± SD) values for all the performance measures in the lower body (LB) and upper body (UB) groups.

	Group	Baseline	Post-test
Vertical Jump without arms (cm)	Lower Body (n=18)	32.7 ± 4.7	32.6 ± 4.4
	Upper Body (n=17)	32.3 ± 4.8	32.1 ± 4.9
Vertical Jump with arms (cm)	Lower Body (n=18)	40.6 ± 6.3	41.1 ± 5.6
	Upper Body (n=17)	38.3 ± 5.6	39.0 ± 6.7
Pushups* (# of repetitions)	Lower Body (n=18)	8.8 ± 6.7	11.6 ± 6.9
	Upper Body (n=16)	6.3 ± 4.7	11.5 ± 6.2
Left grip * (kg)	Lower Body (n=18)	21.1 ± 6.1	22.2 ± 6.1
	Upper Body (n=16)	20.9 ± 6.6	21.6 ± 6.6
Right grip (kg)	Lower Body (n=18)	23.2 ± 6.9	23.9 ± 6.5
	Upper Body (n=17)	23.1 ± 6.1	23.7 ± 5.9

*= Significant main effect for time

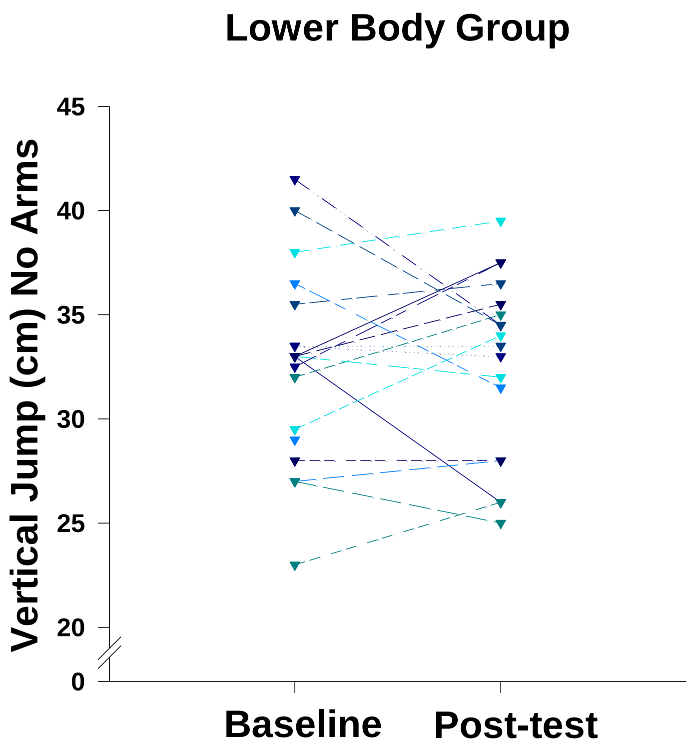

Figure 9. Countermovement jump without arms, baseline and post-test for lower body group.

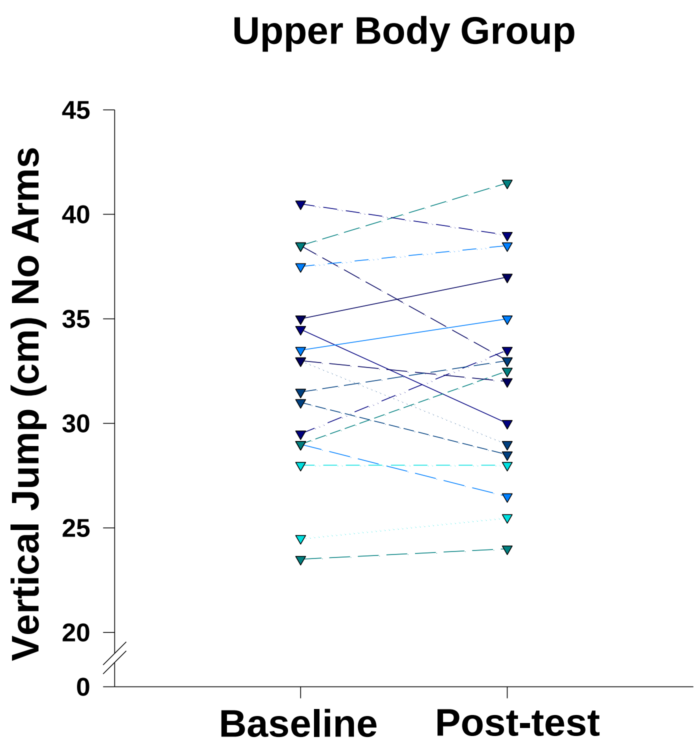

Figure 10. Countermovement jump without arms baseline and post-test for upper body group.

4.3 Countermovement Jump with arms

The best of three trials was also used to examine a countermovement jump with the use of arms. Groups did not differ significantly at baseline for this measure (*P*=0.2). The results of a separate, two way repeated measures ANOVA revealed no significant main effect for time (*P*=0.5) or group (*P*=0.2) (please refer to table 4). There was also no significant interaction effect (*P*=0.9).

4.4 Grip Strength and Pushups

Right grip between groups did not differ significantly at baseline (*P*=0.9). A two way repeated measures ANOVA for right grip did not display a significant main effect for time (*P*=0.1) or group (*P*= 0.9). There was also no significant interaction effect (*P*= 1.0). Groups did not significantly differ at baseline for left grip (*P*=0.9) (please refer to table 4). A two way repeated measures ANOVA for left grip displayed a significant main effect for time (*P*=0.02) but not for group (*P*=0.9). There was also no significant interaction effect (*P*=0.6).

Pushups displayed no significant difference between groups at baseline (*P*=0.07). Pushups displayed a significant main effect for time (*P*= <0.01) but not for group (*P*=0.5). There was no significant interaction effect (*P*=0.13).

4.5 Strength measures

Results for strength measures are displayed in Table 5. In the present study, the participants experienced a significant increase in strength for squats (*P*= <0.05), lunges (*P*= <0.05), chest press (*P*= <0.05), and biceps curl (*P*= <0.05). The strength measures were not an official outcome measure since no blinded observers were used and tests were only done based on group assignment (lower body group performed squats and lunges; and the upper body group performed chest press and biceps curl). In addition, not all participants completed the post-test for all the strength measures due to sport and school commitments.

Table 5: Results of the 10RM testing. Note that the lower body group performed the squat and lunge test, while the upper body group performed the chest press and the biceps curl test.

Exercise	N	Baseline	Post-test	% Change
Squat (kg)	14	20.8 ± 8.7	33.4 ± 10.8	61%
Lunge combined (kg)	13	12.4 ± 4.1	19.5 ± 6.3	56%
Chest press (kg)	15	14.3 ± 3.4	19.3 ± 4.9	34%
Biceps curl per arm (kg)	15	4.9 ± 1.2	6.4.± 1.5	30%

5. Discussion

The purpose of this study was to determine if a strength training intervention for the lower body would produce a change in countermovement jump height without arms in athletic female children aged 10-14 years old, above and beyond normal growth and development. Analyses revealed no significant differences between experimental and control groups at baseline or post-test, and neither group improved.

To date, there have been more studies showing no difference between intervention and control groups (Faigenbaum et al. 1993; Faigenbaum et al. 1996 Faigenbaum et al 2002; Faigenbaum et al. 2005; and Faigenbaum et al. 2007; Lillegard et al. 1997) than there have been showing a difference between groups (Santos and Janeira 2012; Christou et al. 2006; Hetzler et al. 1997; Weltman et al. 1986). These same studies have not involved girls exclusively and only three have involved girls at all. The present study did not support the hypothesis of a change in vertical jump height in this population due to a strength training intervention. Considering that there have been mixed results in the literature regarding strength training and increases in vertical jump, it is important to know why the results of this study differ from some other studies and why no significant results were found. Possible reasons include baseline ability, other sports and activities, the velocity of movement in training, workout adherence, frequency of training, familiarization to the testing procedures, intensity of training, duration of training, measurement device issues, age, and maturation. In the sections below, each will be discussed in detail.

5.1 Baseline Ability

Judging by the mean jump heights of the participants compared to the literature, it appears they performed the test well prior to beginning the strength training program. The mean jump height was 25.1 ± 5.8cm for females from Ortega et al. (2011), which involved 3428 males and females 12.5-17.5 years old. Furthermore, the mean jump for 13 and 14 year old females was 24 ± 5.6 cm and 24.9 ± 5.9cm respectively. The mean jump height of the participants in this study was 32.6 cm ± 4.7 cm at baseline, which would put the participants of the present study in the 90th percentile for 14 year olds according to Ortega et al. (2011). An important note is that the participants in Ortega et al. (2011) performed a countermovement jump with the use of arms on a contact mat and not a Belt Jump, so results must be interpreted with caution. Given the small difference scores between baseline and post-test of intervention and control groups (2.1 cm) seen in the literature for vertical jump as a result of strength training (Harries, Lubans, and Callister 2012), a higher mean at baseline would suggest a smaller possibility for an increase.

5.2 Risk of bias

A meta-analysis by Harries, Lubans, and Callister (2012) examined 14 vertical jump studies for bias and determined that six had a medium risk of bias and the remaining eight had a high risk of bias. Bias and heterogeneity of findings definitely make interpreting and comparing results more difficult and one needs to be aware of such limitations.

5.2.1 Blinded observers

The absence of blinded observers in most training studies can be an important possible source of bias (Schulz et al. 1995). None of the studies examined in the literature review stated whether or not blinded observers were used. Furthermore, a systematic review and meta-analysis by Harries, Lubans, and Callister (2012) did not contain any studies that used blinded observers. Blinding of observers can help with study quality (Schulz et al. 1995), and studies that do not include blinded observers should be interpreted with caution. The present study used a blinded observer in order to decrease bias.

5.2.2 Randomization

Lack of randomization can possibly lead to bias (Olivo et al. 2008). One of the strengths of the present study was the use of a randomized active control group. The goal was to attempt to eliminate sources of bias in order to get an accurate depiction of the results. Approximately half of the studies in the literature review for the present study were randomized which is in agreement with a systematic review by Harries, Lubans, and Callister (2012) who reported that 50% included participants that were randomly assigned to group and only one actually described the randomization process used. However, of the 25 vertical jump studies (Harries, Lubans, and Callister 2012) (all intervention types) only five included a control group, whereas the rest did not, so the stated random group assignment was not a true randomization. Bias can arise in situations that lack a true control group (randomized to control group) according to Harries, Lubans, and Callister (2012).

5.2.3 Follow up assessments

All together, 35 out of 40 participants completed follow up assessments (87.5%). A value over 80% has been shown to be indicative of good quality in a study (Harries Lubans, and Callister (2012). It does not appear this issue was a factor in the present study due to the high percentage of participants who completed their follow up assessments.

5.3 Activity minutes during study

The participants in the present study were very active in a number of different sports. The lower body group partook in 3228.4 ± 2134.6 minutes throughout the intervention, and the upper body group partook in 2784.7 ± 1525.6 minutes throughout the intervention. Activity minutes compared between groups were not significantly different. In terms of comparison to other studies, participants in Santos and Janeira (2012) totaled 3300 minutes, whereas Christou et al. (2006) totaled 8320 minutes. The former is only slightly higher and the latter is much higher than the present study. The difference lies in the fact that Christou et al. (2006) used a whole team that each had the same schedule in the same sporting season (in season), whereas participants in the present study came from a variety of sports, in differing seasons, with a wide range of time commitments. The sports represented were basketball, volleyball, soccer, football, dance, hockey, baseball, swimming, ringette, gymnastics, and track and field. It is possible that the participants of the present study were fatigued and did not recover properly from exercise. Adequate recovery is needed in order to maximize benefits from training (Faigenbaum et al. 2009). The participants were all extremely busy athletes who often came to training directly from practice or games. According to Faigenbaum et al. (2009) and Pack, Cotten, and Biasiotto (1974), the performances of powerful or fast movements are affected by fatigue. It is possible that participants were fatigued at post-test as well. However, due to the 10RM strength improvements and the fact that participants in Christou et al. (2006) had much higher activity levels than the present study and saw significant differences between groups, this would suggest that fatigue did not have a large influence on the outcome. Furthermore, Christou et al. (2006) also stated that a large amount of activity minutes (when there is a significant change) make it difficult to determine how much of the results are due to the activity and how much are due to training. It is possible that studies that showed significant differences received most of the benefits from the sport itself rather than the specific research resistance training.

5.4 Velocity specificity of training

Force and velocity both contribute to the performance of an explosive movement like the vertical jump (Cormie, McGuigan and Newton 2011). Relative contribution depends on a number of factors like training state and training age (Cormie, McGuigan, and Newton 2011). It has been shown that children can increase strength in response to strength training (Malina 2006). A very common mechanism for strength increase in adults is an increase in muscle cross sectional area (Sale 1988). There is limited evidence that suggests that children can increase strength via increases in muscle cross sectional area (Malina 2006). Instead children appear to increase strength primarily via neural mechanisms (Malina 2006). If however, the child has reached or exceeded puberty, the potential for an increase in cross sectional area will be increased (Christou et al. 2006; Hetzler et al.1997).

It appears that the increases in strength that occurred in this study did not make enough of a contribution to the performance of the vertical jump. It appears that in order to increase a powerful movement like vertical jump in children, a larger velocity during training might be needed in order to do so. Originally, the training plan for the present study did include faster training velocities in the last one quarter of the intervention to attempt to increase explosive power in the legs. However, given the emphasis on safety and proper teaching, it was determined that foregoing the increased training velocities would be the best idea. Faigenbaum et al. (2009) stated that motor performance in children and youth will improve more when it is specific in terms velocity, force and type of contraction. Miller, Cheatham, and Patel (2010) revealed that the velocity of a muscle contraction is a big factor in neural changes with training.

Furthermore, Harries Lubans, and Callister (2012) revealed that plyometric training was more effective for increasing vertical jump height than strength training alone. Given the larger effects seen in vertical jump due to plyometric training compared to strength training and the lack of improvement in the present study it appears that for athletic children to improve vertical jump, faster training velocities might be required.

5.5 Adherence

Falk and Tenenbaum (1996) indicated that low adherence can affect the results of a study. Most studies have not reported adherence rates, but those that have, reported rates of at least 90%. Low adherence means that there is less exposure to the stimulus. Falk and Mor (1996) trained children twice per week for 12 weeks with an adherence rate of 90%. Rians et al. (1987) trained three times per week for 14 weeks with an adherence rate of 91.5%. The participants in the present study attended on average 19.8 sessions for an adherence rate of 82.5%, which appears to be lower than what is in the literature. Faigenbaum et al. (1993) showed an adherence rate of 97.4% however the duration of the intervention was eight weeks twice a week for a mean of 15.6 sessions. A large difference was seen with Weltman et al. (1986), which had an adherence rate of 91.5%. The duration of the intervention was 14 weeks, three times per week for a total of 38 sessions. The realities of studying athletic children make it more difficult to achieve 100% attendance. They are usually extremely busy with multiple sport commitments and often have to choose between commitments on a given night. Sometimes, the intervention study was at the losing end of that choice. It appears that other studies have yielded higher adherence rates. Attending more sessions will likely lead to better results (Falk and Tenenbaum 1996). It means more exposure of the neuromuscular system to the training stimulus, and more opportunity to practice the skill. However, participants in our study did appear to make improvements in their 10RM strength for both the lower body and upper body groups. Therefore it appears that adherence may not have been as large a factor but more research is required to determine the threshold for changes in motor performance in children.

5.6 Frequency

Recommended training frequency will depend on a few factors like training experience, training status, the goals of the training and available time (Miller, Cheatham, and Patel 2010). Falk and Tenenbaum (1996) reported that two days per week training showed similar benefits to three days per week training, although this study used males and measured strength not motor performance. The question is whether or not this increase in strength makes enough of a contribution to increase vertical jump height. It appears that it may not make enough of a contribution. This statement would be in agreement with the present study, given that there was a significant increase in strength without an increase in vertical jump height. In the instances that strength does make a substantial contribution to jump height, it might take a higher training frequency than is regularly done with this population (Weltman et al. 1986). However, comparisons in frequency are extremely scarce for this population for this performance measure (Behm et al. 2008).

5.7 Familiarization

It was proposed that the jump landing tasks would be sufficient familiarization to the vertical jump task. It is possible that this was not the case. Nuzzo, Anning, and Scharfenberg (2011) stated the need for extensive familiarization prior to testing motor skills in order to ensure more reliable results. It is possible that the participants in the study did not jump their maximum heights due to lack of familiarization. Limited familiarization would suggest a larger variability across the different jump attempts. There was a slightly increased coefficient of variation (CV) in this study for no arms jumps (7.3%) and arms jumps (8.7%) compared to previously reported values of 4.1% and 4.6% respectively (Markovic et al. 2004). Given that the CV did not exceed appropriate levels (Zady 2009) and that neither group changed their vertical jump heights with additional testing suggests that this was not a main factor.

5.8 Intensity

It has been recommended that children start a resistance training intervention using moderate loads in order to learn proper and safe technique (Faigenbaum et al. 2009). The present study used three sets of 10-15 repetitions at intensities of 50% 10RM, 70% 10RM and 100% 10RM. The 10RM was progressed throughout the intervention. However, a 10RM was maintained as the maximum. A load of 100% 10RM in adults is approximately equivalent to 75% of 1RM (Baechle and Earle 2000), which would certainly fall in the moderate category. There is a possibility that the participants required more repetitions closer to that 100% 10RM range. Behringer et al. (2011) revealed a significant positive correlation between intensity (% of 1RM) and gains in motor performance including vertical jump. This result would suggest perhaps a higher intensity or more sets at the higher intensity could have led to better results. Miller, Cheatham and Patel (2010), and a position stand by Faigenbaum et al. (2009), showed that loads between 10RM and 5RM are also safe for children. In addition, Ramsay et al. (1990) revealed that loads of 70-85% 1RM (5-7 RM) can be used safely with children. However, safe and proper execution is of the utmost importance when dealing with strength training in children. If a higher intensity were to be used, it would require a longer intervention period so that participants could improve their lifting technique to a satisfactory level using lighter loads. Given the more complex task requirement of free weights compared to machines, it is even more imperative that proper form be achieved. After examining the literature, the intensity used in the present study was most likely sufficient. Hetzler et al. (1997) used intensities of 50, 75, 100% 10RM (55/60 to 75% 1RM), Christou et al. (2006) used intensities of 55% to 80% 1RM, Santos and Janeira (2012) used intensities of 55/60 to 75%1RM. All of these studies demonstrated a significant difference in vertical jump height due to strength training. On another note, the increases in strength of the present study were in line with what has been demonstrated in previous studies (Falk and Tenenbaum 1996). Increases in strength of 13-30% have been reported as typical by Falk and Tenenbaum, who also mentioned that increases as high as 74% have also been shown.

5.9 Duration

Duration of intervention in relation to gains in motor performance did not reveal a significant positive relationship according to Behringer et al. (2011). This result lends support to a learning effect early on in a training intervention (Malina 2006). It also supports the notion that a lower skill level/training experience at baseline will lead to larger gains than a higher skill level/experience at baseline (Ziv and Lidor 2010). This determination by Behringer et al. (2011) is not consistent with the trend seen in the vertical jump literature in children. All studies showing a difference used at least 10 weeks of training, whereas the studies not showing a difference used six to eight weeks, except for one (Lillegard et al. 1997). Interestingly, Behringer et al. (2010) revealed that duration and strength gains do show a significant positive relationship. It does not appear that duration was a big factor in the vertical jump outcome of the present study but it may have been important in influencing the strength measures.

5.10.0 Measurement device

It is possible the reliability of the Belt Jump was not sufficient. Women only displayed moderate reliability according to Slinde et al. (2008), so it is possible female children were comparable or worse. Reliability measurements for the Belt Jump in children are lacking. Assessing the reliability of the Belt Jump for this population would help determine if it is appropriate for this population. Markovic et al. (2004) revealed a coefficient of variation of 4.1% (ICC= 0.94) for a Belt Jump without the use of arms, and 4.6% (ICC= 0.93) with arms, although this was for men. The present study revealed a coefficient of variation of 7.3% for the jump without arms and 8.7% for the jump with arms, over the 12 weeks. Although higher than Markovic et al. (2004), the coefficient of variation of the present study does not suggest poor reliability of the Belt Jump in females (Zady 2009).

5.11.0 Age and maturation

The relationship of vertical jump with age and maturation in females, shows a similar trend to that of strength gains and age. That relationship is an increasing trend up until puberty or a period past puberty, which is followed by a period of leveling off (Naughton et al. 2000). When this relationship was examined by age, increasing trends followed by plateaus have been shown up until age 14 for jump and reach tests (Branta et al. 1984) and 13-16 for contact mat tests (Kellis et al. 1999). Significant age differences in vertical jump up until age 12, followed by a plateau have been shown for contact mat tests as well (Taylor et al. 2010). Östenberg et al. (2000) used a Belt Jump type device in female soccer players under 20 and over 20 years of age. The means of the jumps with the use of arms was 38.6 ± 9.9 cm for the under 20 females, and 40

± 10 cm for the over 20 females. There were no significant differences between the means of the under 20 females and over 20 females (P=0.45). It appears that the leveling off of performance might continue into older ages. Of note, Dopsaj et al. (2012) demonstrated jump heights of 45 ± 4.2cm on a Belt Jump with the use of arms. It is not known whether these participants had better and more extensive training or simply a naturally better jumping ability. Due to the age of participants in the present study, and the trends seen in the literature regarding a leveling off of performance in the vertical jump in this age group, it is possible that participants were experiencing a leveling off of performance. In this case improvements in vertical jump would not be likely.

5.12.0 Previous strength training experience

The exclusion criteria for the present study stated no formal strength or resistance training experience in the last six months. Blimkie et al. (1992) suggests that, ensuring similar skill level and training background prior to an intervention is appropriate. However some participants were definitely more skilled at lifting than others, so it is possible that previous training experience still had a positive effect on their ability to complete the tasks required of them. It is also possible that some participants were able to learn the skills of the lift faster than others. The degree to which this factor affected the results was most likely minor because it is unlikely that the lifting experience of 10-14 year old participants is so vast that their increased experience in lifting would limit their ability to see gains.

5.13.0 Type of sport participation

There was considerable heterogeneity in terms of type of sport participation. Some sports inherently involve a larger amount of certain skills than others. For example some sports involve more jumping than others. If a child participates in a sport that involves a lot of jumping, that might explain high baseline vertical jump ability if one was to examine such a quality. A large number of participants in the present study played basketball and volleyball in which there is a lot of jumping. This amount of jumping might have contributed to their high jumping ability.

5.14.0 Grip Strength and Pushups

The only grip strength measure that changed significantly from baseline to post-test was left grip strength. Even though the upper body group trained specifically with the upper body, most of the exercises required holding the weights in the palms up position where the weights could rest against the palm with less emphasis on gripping. The weights were also fairly light. In comparison, the lower body group performed lunges, which required holding heavier weights for a longer period in both hands, so it is possible that an increased grip stimulus was present. Right grip demonstrated a non-significant increase for the upper and lower body groups and increased by virtually identical amounts (+0.63). The majority of the children were right handed, suggesting that the right hand was stronger and the left had more chance to improve, which could explain the improvement across both groups in left grip strength.

Pushups displayed a significant increase from baseline to post-test. There was no significant difference between the lower body and upper body groups, although the upper body group did increase more than the lower body group. It is possible that both groups practiced pushups throughout their sport practices, but with the extra stimulus provided by the upper body group's training, it might explain the slightly larger increase by the upper body (non significant).

6. Future directions

Given the small amount of research on female children in training studies, there are a number of avenues to explore. First, participants in this study were chosen based on age and activity participation. It is well documented that children of all ages and maturation levels can increase their strength (Faigenbaum et al. 2009, Faigenbaum 2000, and Malina 2006). It might be interesting to split up participants based on pubertal status and examine the effect of training for vertical jump based on those categories. Participants were not split up after the fact because there were not enough cases per category to accurately examine the results based on pubertal score.

Second, the effect of ballistic exercises including jump squat training would be great to explore in female children. These training elements have been shown to increase vertical jump due to their effect on the force and velocity component of the jump (Cormie, McGuigan, and Newton 2011). Ballistic exercises have also shown to be more effective than strength training alone for increasing vertical jump (Cormie, McGuigan, and Newton 2011) due to their augmentation of movement velocity, force, and acceleration. Since there was no change in the present study, examining the effect of ballistic methods would be a great next step.

Third, comparing Biodex data to vertical jump data for all the participants might have allowed for examination of changes in velocity and power of different movements and relate them to vertical jump. However, this would probably involve changing the training velocities, which again was planned but was not realized.

Fourth, the limited availability of reliability of testing devices in female children has been noted previously. Examining the reliability of the Belt Jump and other devices in female children for the purposes of vertical jump assessment would be of good value.

.

7. Conclusion

This thesis focused on the effect of strength training on the vertical jump ability of athletic female athletes aged 10-14 years. The results revealed no change as a result of time, group assignment or an interaction of the two for CMJ without arms, CMJ with arms, or right grip despite the fact that there was a substantial change in leg strength. There were however, significant main effects for time for left grip and pushups however there was no interaction effect for these measures. This study filled a gap in the literature due to the fact that there are no female only studies examining strength training and vertical jump ability. The study also had a strong design including the use of blinded observers, randomization to groups, the reporting of follow-up assessments, accounting for baseline differences, reporting of power and sample size calculations, and the use of an active control group to serve as comparison. A good number of training studies do not include these strong design elements (Harries, Lubans, and Callister 2012) so their results should be interpreted with caution. Although there were limitations to the present study, it is clear that the training stimulus provided was not sufficient to elicit improvements in vertical jump in this population.

8. Practical Implications

Through observation, it is assumed that most strength training interventions will increase the vertical jump height of young female athletes. However, the training stimulus experienced by the participants of the current study, was not sufficient to elicit a change in vertical jump height. This finding would suggest a recommendation of more appropriate prescriptions possibly involving exercises with more specific movement velocity, force and acceleration (Faigenbaum et al. 2009).

References

Aboodarda, Saied Jalal, Fatimah Ibrahim, A. H. Mokhtar, Martim W. Thompson, and David G. Behm. 2012. "Acute Neuromuscular and Hormonal Responses to Resistance Exercise using Variable External Resistance Loading." *Journal of Exercise Physiology Online* 15 (6): 1-12.

Aouichaoui, Chirine, Yassine Trabelsi, Ezzdine Bouhlel, Zouhair Tabka, Mohamed Dogui, Jean Paul Richalet, and Annick Bouchez Buvry. 2012. "The Relative Contributions of Anthropometric Variables to Vertical Jumping Ability and Leg Power in Tunisian Children." *Journal of Strength & Conditioning Research* (Lippincott Williams & Wilkins) 26 (3): 777-788.

Aouichaoui, C, C Aouichaoui, Y Trabelsi, Z Tabka, M Dogui, JP Richalet, and E Bouhlel. "Effect of Anthropometric Characteristics and Socio-Economic Status on Vertical Jumping Performances in Tunisian Athletic Children." *American Journal of Sports Science and Medicine 2, no. 1* (2014): 6-16

Ashley, C. D. and L. W. Weiss. 1994. "Vertical Jump Performance and Selected Physiological Characteristics of Women." *Journal of Strength & Conditioning Research (Allen Press Publishing Services Inc.)* 8 (1): 5-11.

Baechle, T. R. and R. W. Earle. 2000. *Essentials of Strength Training and Conditioning. 2nd Ed*. Champaign, Ill.; United States: Human Kinetics.

Baker, D. 2001. "Acute and Long-Term Power Responses to Power Training: Observations on the Training of an Elite Power Athlete. / Reponses a Long Terme Et Immediates a Un Entrainement De Puissance, Observations De l'Entrainement d'Un Athlete Specialise Dans Les Sports De Puissance." *Strength & Conditioning Journal* 23 (1): 47-56.

Behm, David G., Avery D. Faigenbaum, Baraket Falk, and Panagiota Klentrou. 2008. "Canadian Society for Exercise Physiology Position Paper: Resistance Training in Children and Adolescents." *Applied Physiology, Nutrition & Metabolism* 33 (3): 547-561.

Behringer, M., A. Vom Heede, Z. Yue, and J. Mester. 2010. "Effects of Resistance Training in Children and Adolescents: A Meta-Analysis." *Pediatrics* 126 (5): e1199-210.

Blimkie, C. J. R. 1992. "Resistance Training during Pre- and Early Puberty: Efficacy, Trainability, Mechanisms, and Persistence." *Canadian Journal of Sport Sciences* 17 (4): 264-279.

Blimkie, C. J. R. and D. G. Sale. 1998. "Strength Development and Trainability during Childhood." Pediatric anaerobic performance, Champaign, Ill.; United States: Human Kinetics, c1998, p.193-224. 32p.

Bobbert, M. F. 1990. "Drop Jumping as a Training Method for Jumping Ability." *Sports Medicine* 9 (1): 7-22.

Bobbert, M. F., K. G. Gerritsen, M. C. Litjens, and A. J. Van Soest. 1996. "Why is Countermovement Jump Height Greater than Squat Jump Height?" *Medicine and Science in Sports and Exercise* 28 (11): 1402-1412.

Bobbert, Maarten, F. and L. J. Richard Casius. 2005. "Is the Effect of a Countermovement on Jump Height due to Active State Development?" *Medicine & Science in Sports & Exercise* 37 (3): 440-446.

Bosco, C., P. Luhtanen, and P. V. Komi. 1983. *A Simple Method for Measurement of Mechanical Power in Jumping*. Vol. 50.

Bottaro, Martim, Lee Brown E., Rodrigo Celes, Saulo Martorelli, Rodrigo Carregaro, and Carlos de Brito. 2011. "Effect of Rest Interval on Neuromuscular and Metabolic Responses between Children and Adolescents." *Pediatric Exercise Science* 23 (3): 311-321.

Buckthorpe, Matthew, John Morris, and Jonathan Folland P. 2012. "Validity of Vertical Jump Measurement Devices." *Journal of Sports Sciences* 30 (1): 63-69.

Burt, C. W. and M. D. Overpeck. 2001. "Emergency Visits for Sports-Related Injuries." *Annals of Emergency Medicine* 37 (3): 301-308.

Cahill, B. R. and E. H. Griffith. 1978. "Effect of Preseason Conditioning on the Incidence and Severity of High School Football Knee Injuries." *American Journal of Sports Medicine* 6 (4): 180-184.

Chelly, M. S., M. Fathloun, N. Cherif, M. Ben Amar, Z. Tabka, and E. Van Praagh. 2009. "Effects of a Back Squat Training Program on Leg Power, Jump, and Sprint Performances in Junior Soccer Players." *Journal of Strength and Conditioning Research / National Strength & Conditioning Association* 23 (8): 2241-2249.

Christou, M., I. Smilios, K. Sotiropoulos, K. Volaklis, T. Pilianidis, and S. P. Tokmakidis. 2006. "Effects of Resistance Training on the Physical Capacities of Adolescent Soccer Players." *Journal of Strength & Conditioning Research (Allen Press Publishing Services Inc.)* 20 (4): 783-791.

Cormie, P. 2009. "A series of investigations into the effect of strength level on muscular power in athletic movements." PHD Dissertation, Edith Cowan University.

Cormie, P., J. M. McBride, and G. O. McCaulley. 2009. "Power-Time, Force-Time, and Velocity-Time Curve Analysis of the Countermovement Jump: Impact of Training." *Journal of Strength & Conditioning Research (Lippincott Williams & Wilkins)* 23 (1): 177-186.

Cormie, Prue, Michael McCuigan R., and Robert Newton U. 2011. "Developing Maximal Neuromuscular Power." *Sports Medicine* 41 (1): 17-38.

Cormie, Prue, Michael McGuigan R., and Robert Newton U. 2011. "Developing Maximal Neuromuscular Power: Part 2 - Training Considerations for Improving Maximal Power Production." *Sports Medicine* 41 (2): 125-146.

Cress, N. M., K. S. Peters, and J. M. Chandler. 1992. "Eccentric and Concentric Force-Velocity Relationships of the Quadriceps Femoris Muscle." *Journal of Orthopaedic & Sports Physical Therapy* 16 (2): 82-86.

Cronin, J. B., P. J. McNair, and R. N. Marshall. 2003. "Force-Velocity Analysis of Strength-Training Techniques and Load: Implications for Training Strategy and Research." *Journal of Strength & Conditioning Research (Allen Press Publishing Services Inc.)* 17 (1): 148-155.

Davies, Patricia L. and James D. Rose. 1999. "Assessment of Cognitive Development in Adolescents by Means of Neuropsychological Tasks." *Developmental Neuropsychology* 15 (2): 227.

DiStefano, Lindsay J., J. T. Blackburn, Stephen W. Marshall, Kevin M. Guskiewicz, William E. Garrett, and Darin A. Padua. 2011. "Effects of an Age-Specific Anterior Cruciate Ligament Injury Prevention Program on Lower Extremity Biomechanics in Children." *American Journal of Sports Medicine* 39 (5): 949-957.

DiStefano, Lindsay J., Darin A. Padua, Michael J. DiStefano, and Stephen W. Marshall. 2009. "Influence of Age, Sex, Technique, and Exercise Program on Movement Patterns After an Anterior Cruciate Ligament Injury Prevention Program in Youth Soccer Players." *American Journal of Sports Medicine* 37 (3): 495-505.

Dopsaj, Milivoj, Nemanja Copic, Goran Nešic, and Milan Sikimic. 2012. "Jumping Performance in Elite Female Volleyball Players Relative to Playing Positions: A Practical Multidimensional Assessment Model." *Serbian Journal of Sports Sciences* 6 (2): 61-69.

Edwen, C. E., J. B. Thorlund, S. P. Magnusson, F. Slinde, U. Svantesson, L. Hulthen, and P. Aagaard. 2013. "Stretch-Shortening Cycle Muscle Power in Women and Men Aged 18-81 Years: Influence of Age and Gender." *Scandinavian Journal of Medicine & Science in Sports*.

Faigenbaum, A. D., W. J. Kraemer, C. J. Blimkie, I. Jeffreys, L. J. Micheli, M. Nitka, and T. W. Rowland. 2009. "Youth Resistance Training: Updated Position Statement Paper from the National Strength and Conditioning Association." *Journal of Strength & Conditioning Research (Lippincott Williams & Wilkins)* 23 (5): S60-79.

Faigenbaum, A. D., R. L. Loud, J. O'Connell, S. Glover, J. O'Connell, and W. L. Westcott. 2001. "Effects of Different Resistance Training Protocols on Upper-Body Strength and Endurance

Development in Children." *Journal of Strength & Conditioning Research (Allen Press Publishing Services Inc.)* 15 (4): 459-465.

Faigenbaum, A. D., J. E. McFarland, E. Buchanan, N. A. Ratamess, J. Kang, and J. R. Hoffman. 2010. "After-School Fitness Performance is Not Altered After Physical Education Lessons in Adolescent Athletes." *Journal of Strength and Conditioning Research / National Strength & Conditioning Association* 24 (3): 765-770.

Faigenbaum, A. D., J. E. McFarland, F. B. Keiper, W. Tevlin, N. A. Ratamess, J. Kang, and J. R. Hoffman. 2007. "Effects of a Short-Term Plyometric and Resistance Training Program on Fitness Performance in Males Age 12 to 15 Years." *Journal of Sports Science and Medicine* 6 (4): 519-525.

Faigenbaum, A. D., L. Milliken, L. Moulton, and W. L. Westcott. 2005. "Early Muscular Fitness Adaptations in Children in Response to Two Different Resistance Training Regimens." *Pediatric Exercise Science* 17 (3): 237-248.

Faigenbaum, A. D., L. A. Milliken, R. LaRosa Loud, B. T. Burak, C. L. Doherty, and W. L. Westcott. 2002. "Comparison of 1 and 2 Days Per Week of Strength Training in Children." *Research Quarterly for Exercise and Sport* 73 (4): 416-424.

Faigenbaum, A. D. and G. D. Myer. 2010. "Resistance Training among Young Athletes: Safety, Efficacy and Injury Prevention Effects." *British Journal of Sports Medicine* 44 (1): 56-63.

Faigenbaum, Avery D., Anne C. Farrell, Tracy Radler, Dan Zbojovsky, Donald A. Chu, Nicholas A. Ratamess, Jie Kang, and Jay R. Hoffman. 2009. ""Plyo Play": A Novel Program of Short Bouts of Moderate and High Intensity Exercise Improves Physical Fitness in Elementary School Children." *Physical Educator* 66 (1): 37-44.

Faigenbaum, Avery D., William J. Kraemer, Cameron J. R. Blimkie, Ian Jeffreys, Lyle J. Micheli, Mike Nitka, and Thomas W. Rowland. 2009. "Youth Resistance Training: Updated Position Statement Paper from the National Strength and Conditioning Association." *Journal of Strength & Conditioning Research (Lippincott Williams & Wilkins)* 23: S60-S79.

Faigenbaum, Avery D. and Gregory D. Myer. 2010. "Pediatric Resistance Training: Benefits, Concerns, and Program Design Considerations." *Current Sports Medicine Reports (American College of Sports Medicine)* 9 (3): 161-168.

Faigenbaum, Avery D., Leonard D. Zaichkowsky, Wayne L. Westcott, Lyle J. Micheli, and Allen F. Fehlandt. 1993. "The Effects of a Twice-a-Week Strength Training Program on Children." *Pediatric Exercise Science* 5 (4): 339-346.

Faigenbaum, A. D., W. L. Westcott, L. J. Micheli, A. R. Outerbridge, C. J. Long, R. LaRosa-Loud, and L. D. Zaichkowsky. 1996. "The Effects of Strength Training and Detraining on Children." *Journal of Strength & Conditioning Research (Allen Press Publishing Services Inc.*) 10 (2): 109-114.

Falk, B. and G. Tenenbaum. 1996. "The Effectiveness of Resistance Training in Children: A Meta-Analysis." *Sports Medicine* 22 (3): 176-186.

Fath, Florian, Anthony J. Blazevich, Charlie M. Waugh, Stuart C. Miller, and Thomas Korff. 2013. "Interactive Effects of Joint Angle, Contraction State and Method on Estimates of Achilles Tendon Moment Arms." *Journal of Applied Biomechanics* 29 (2): 241-244.

Feltner, Michael E., Daniel J. Fraschetti, and Robert J. Crisp. 1999. "Upper Extremity Augmentation of Lower Extremity Kinetics during Countermovement Vertical Jumps." *Journal of Sports Sciences* 17 (6): 449-466.

Faul, F., Erdfelder,E., Buchner,A., & Lang, A.-G. 2009. “Statistical power analysis using G*Power 3.1: Tests for correlation and regression analysis.” *Behavior Research Methods*, 41: 1149-1160.

Fleck, S. J. and W. J. Kraemer. 2004. *Designing Resistance Training Programs. 3rd Ed*. Champaign, Ill.; United States: Human Kinetics.

Hara, Mikiko, Akira Shibayama, Daisuke Takeshita, Dean C. Hay, and Senshi Fukashiro. 2008. "A Comparison of the Mechanical Effect of Arm Swing and Countermovement on the Lower Extremities in Vertical Jumping." *Human Movement Science* 27 (4): 636-648.

Harman, E. A., M. T. Rosenstein, P. N. Frykman, and R. M. Rosenstein. 1990. "The Effects of Arms and Countermovement on Vertical Jumping." *Medicine and Science in Sports and Exercise* 22 (6): 825-833.

Harries, S. K., D. R. Lubans, and R. Callister. 2012. "Resistance Training to Improve Power and Sports Performance in Adolescent Athletes: A Systematic Review and Meta-Analysis." *Journal of Science and Medicine in Sport* 15 (6): 532-540.

Heidt Jr., R. S., L. M. Sweeterman, R. L. Carlonas, J. A. Traub, and F. X. Tekulve. 2000. "Avoidance of Soccer Injuries with Preseason Conditioning. / Prevention Des Blessures Au Football Grace Au Conditionnement Physique d'Avant Saison." *American Journal of Sports Medicine* 28 (5): 659-662.

Hejna, W. F., A. Rosenberg, D. J. Buturusis, and A. Krieger. 1982. "Prevention of Sports Injuries in High School Students through Strength Training." *National Strength & Conditioning Association Journal* 4 (1): 28-31.

Hetzler, R. K., C. DeRenne, B. P. Buxton, K. W. Ho, D. X. Chai, and G. Seichi. 1997. "Effects of 12 Weeks of Strength Training on Anaerobic Power in Prepubescent Male Athletes." *Journal of Strength and Conditioning Research* 11 (3): 174-181.

Hewett, Timothy E., Gregory D. Myer, and Kevin R. Ford. 2004. "Decrease in Neuromuscular Control About the Knee with Maturation in Female Athletes." *Journal Of Bone & Joint Surgery, American Volume 86-A, no. 8*: 1601-1608.

Hill, Gerald N., Hill, Kathleen T., (1981-2005). “Child” *The Free Dictionary*. (Retrieved 02/05, 2013). http://legal-dictionary.thefreedictionary.com/child

Hopkins, W. G. “Analysis of Covariance” *A new view of Statistics.* (2002): Last modified January 31 2003. http://sportsci.org/resource/stats/index.html

Hopkins, W. G. “Estimating Sample Size for Magnitude-Based Inferences.” *A new view of Statistics.* (2007): Last modified June 2011. http://sportsci.org/resource/stats/index.html

Hopkins, W. G. “Repeated Measures Models.” *A new view of Statistics.* (2012): Last modified March 5 2012. http://sportsci.org/resource/stats/index.html

Ignjatovic, Aleksandar, Ratko Stankovic, Dragan Radovanovic, Živorad Markovic, and Jan Cvecka. 2009. "Resistance Training for Youths. / Trening Sa Opterecenjem Kod Mladih." *Facta Universitatis: Series Physical Education & Sport* 7 (2): 189-196.

Kawamori, N. and G. G. Haff. 2004. "The Optimal Training Load for the Development of Muscular Power." *Journal of Strength & Conditioning Research (Allen Press Publishing Services Inc.)* 18 (3): 675-684.

Kellis, S. E., G. K. Tsitskaris, M. D. Nikopoulou, and K. C. Mousikou. 1999. "The Evaluation of Jumping Ability of Male and Female Basketball Players According to their Chronological Age and Major Leagues." *Journal of Strength & Conditioning Research* 13 (1): 40-46.

Kirby, R. F. 1991. *Kirby's Guide to Fitness and Motor Performance Tests*. Cape Girardeau, Mo.; United States: BenOak Publishing Company.

Kirby, Tyler, J., Jeffrey McBride M., Tracie Haines L., and Andrea Dayne M. 2011. "Relative Net Vertical Impulse Determines Jumping Performance." *Journal of Applied Biomechanics* 27 (3): 207-214.

Klavora, P. 2000. "Vertical-Jump Tests: A Critical Review." *Strength & Conditioning Journal (Allen Press)* 22 (5): 70-74.

Kotzamanidis, C. 2006. "Effect of Plyometric Training on Running Performance and Vertical Jumping in Prepubertal Males." *Journal of Strength & Conditioning Research (Allen Press Publishing Services Inc.)* 20 (2): 441-445.

Kraemer, William J. and Steven J. Fleck. 2005. *Strength Training for Young Athletes. 2nd Ed*. Champaign, ill.; United States: Human Kinetics.

Kulig, K., J. G. Andrews, and J. G. Hay. 1984. "Human Strength Curves." *Exercise & Sport Sciences Reviews* 12: 417-466.

Lees, Adrian, Jos Vanrenterghem, and Dirk De Clercq. 2004. "Understanding how an Arm Swing Enhances Performance in the Vertical Jump." *Journal of Biomechanics* 37 (12): 1929-1940.

Lidor, Ronnie and Gal Ziv. 2010. "Physical Characteristics and Physiological Attributes of Adolescent Volleyball Players--A Review." *Pediatric Exercise Science* 22 (1): 114-134.

Lillegard, W. A., E. W. Brown, D. J. Wilson, R. Henderson, and E. Lewis. 1997. "Efficacy of Strength Training in Prepubescent to Early Postpubescent Males and Females: Effects of Gender and Maturity." *Pediatric Rehabilitation* 1 (3): 147-157.

Linthorne, Nicholas P. 2001. "Analysis of Standing Vertical Jumps using a Force Platform." *American Journal of Physics* 69 (11): 1198.

Lloyd, Rhodri S., Jon L. Oliver, Michael G. Hughes, and Craig A. Williams. 2009. "Reliability and Validity of Field-Based Measures of Leg Stiffness and Reactive Strength Index in Youths." *Journal of Sports Sciences* 27 (14): 1565-1573.

Malina, R. M. 2006. "Weight Training in Youth -- Growth, Maturation, and Safety: An Evidence-Based Review." *Clinical Journal of Sport Medicine* 16 (6): 478-487.

Markovic, Goran, Drazan Dizdar, Igor Jukic, and Marco Cardinale. 2004. "Reliability and Factorial Validity of Squat and Countermovement Jump tests." *Journal Of Strength & Conditioning Research* (Allen Press Publishing Services Inc.) 18, no. 3: 551-555.

Markovic, Goran and Slobodan Jaric. 2007. "Is Vertical Jump Height a Body Size-Independent Measure of Muscle Power?" *Journal of Sports Sciences* 25 (12): 1355-1363.

McCambridge, T. M. and P. R. Stricker. 2008. "Strength Training by Children and Adolescents." *Pediatrics* 121 (4): 835-840.

Meylan, C, and D Malatesta. 2009. "Effects of in-season plyometric training within soccer practice on explosive actions of young players." *Journal Of Strength & Conditioning Research* (Lippincott Williams & Wilkins) 23, no. 9: 2605-2613.

Miller, M. G., C. C. Cheatham, and N. D. Patel. 2010. "Resistance Training for Adolescents." *Pediatric Clinics of North America* 57 (3): 671-682.

Myer, G. D., A. D. Faigenbaum, D. A. Chu, J. Falkel, K. R. Ford, T. M. Best, and T. E. Hewett. 2011. "Integrative Training for Children and Adolescents: Techniques and Practices for Reducing Sports-Related Injuries and Enhancing Athletic Performance." *The Physician and Sportsmedicine* 39 (1): 74-84.

Myer, G. D., A. D. Faigenbaum, K. R. Ford, T. M. Best, M. F. Bergeron, and T. E. Hewett. 2011. "When to Initiate Integrative Neuromuscular Training to Reduce Sports-Related Injuries and Enhance Health in Youth?" *Current Sports Medicine Reports* 10 (3): 157-166.

Naughton, G., N. Farpour-Lambert, J. Carlson, M. Bradney, and E. Van Praagh. 2000. "Physiological Issues Surrounding the Performance of Adolescent Athletes. / Reponses Physiologiques Accompagnant La Performance Des Athletes Adolescents." *Sports Medicine* 30 (5): 309-325.

Nordin, M. and V. H. Frankel. 2001. *Basic Biomechanics of the Musculoskeletal System. 3rd Ed*. Baltimore, Md.; United States: Lippincott, Williams & Wilkins.

Nuzzo, James, L., Jonathan Anning H., and Jessica Scharfenberg M. 2011. "The Reliability of Three Devices used for Measuring Vertical Jump Height." *Journal of Strength & Conditioning Research (Lippincott Williams & Wilkins)* 25 (9): 2580-2590.

O'Hagan, F. T., D. G. Sale, J. D. MacDougall, and S. H. Garner. 1995. "Comparative Effectiveness of Accommodating and Weight Resistance Training Modes." *Medicine and Science in Sports and Exercise* 27 (8): 1210-1219.

Olivo, Susan Armijo, Luciana Gazzi Macedo, Inae Caroline Gadotti, Jorge Fuentes, Tasha Stanton, and David J. Magee. 2008. "Scales to Assess the Quality of Randomized Controlled Trials: A Systematic Review." *Physical Therapy* 88 (2): 156-175.

Olsen, Odd-Egil, Grethe Myklebust, Lars Engebretsen, Ingar Holme, and Roald Bahr. 2005. "Exercises to Prevent Lower Limb Injuries in Youth Sports: Cluster Randomised Controlled Trial." *BMJ: British Medical Journal (International Edition)* 330 (7489): 449-452.

Ortega, F. B., E. G. Artero, J. R. Ruiz, V. Espana-Romero, D. Jimenez-Pavon, G. Vicente-Rodriguez, L. A. Moreno, et al. 2011. "Physical Fitness Levels among European Adolescents: The HELENA Study." *British Journal of Sports Medicine* 45 (1): 20-29.

Östenberg, Anna, Ewa M. Roos, Charlotte Ekdahl, and Harald P. Roos. 2000. *Physical Capacity in Female Soccer Players - does Age make a Difference?. Vol. 2.*

Ozmun, J. C., A. E. Mikesky, and P. R. Surburg. 1994. "Neuromuscular Adaptations Following Prepubescent Strength Training. / Adaptations Neuromusculaires Suivant Un Entrainement De Force Pour Des Individus Prepubertaires." *Medicine & Science in Sports & Exercise* 26 (4): 510-514.

Michael Pack, D., D. J. Cotten, and J. Biasiotto. 1974. "Effect of Four Fatigue Levels on Performance and Learning of a Novel Dynamic Balance Skill." *Journal of Motor Behavior* 6 (3): 191-197.

Pannucci, C. J. and E. G. Wilkins. 2010. "Identifying and Avoiding Bias in Research." *Plastic and Reconstructive Surgery* 126 (2): 619-625.

Payne, V. G., J. R. Morrow, L. Johnson, and S. N. Dalton. 1997. "Resistance Training in Children and Youth: A Meta-Analysis." *Research Quarterly for Exercise & Sport* 68 (1): 80-88.

Pfeiffer, R. D. and R. S. Francis. 1986. "Effects of Strength Training on Muscle Development in Prepubescent, Pubescent, and Postpubescent Males. / Effets d ' Un Entrainement De Musculation Sur Le Developpement Musculaire Des Garcons Prepuberes, Puberes Et Post-Puberes." *Physician & Sportsmedicine* 14 (9): 134-139;142-143.

Rians, C. B., A. Weltman, B. R. Cahill, C. A. Janney, S. R. Tippett, and F. I. Katch. 1987. "Strength Training for Prepubescent Males: Is it Safe? / Entrainement En Force Pour Des Garcons d ' Age Pre-Pubertaire: Est-Ce Sans Danger ?" *American Journal of Sports Medicine* 15 (5): 483-489.

Ramsay, J. A., C. J. R. Blimkie, K. Smith, S. Garner, J. D. MacDougall, and D. G. Sale. 1990. "Strength Training Effects in Prepubescent Males." *Medicine and Science in Sports and Exercise* 22 (5): 605-614.

Ratamess, Nicholas A., Brent A. Alvar, Tammy K. Evetoch, Terry J. Housh, W. B. Kibler, William J. Kraemer, and N. T. Triplett. 2009. "Progression Models in Resistance Training for Healthy Adults." *Medicine & Science in Sports & Exercise* 41 (3): 687-708.

Robertson, Robert J., Fredric L. Goss, Joseph L. Andreacci, John J. Dube, Jason J. Rutkowski, Krisi Frazee M., Deborah J. Aaron, Kenneth Metz F., Ruth A. Kowallis, and Brooke M. Snee. 2005. "Validation of the Children's OMNI-Resistance Exercise Scale of Perceived Exertion." *Medicine & Science in Sports & Exercise* 37 (5): 819-826.

Rubley, M. D., A. C. Haase, W. R. Holcomb, T. J. Girouard, and R. D. Tandy. 2011. "The Effect of Plyometric Training on Power and Kicking Distance in Female Adolescent Soccer Players." *Journal of Strength and Conditioning Research / National Strength & Conditioning Association* 25 (1): 129-134.

Rutherford, O. M. and D. A. Jones. 1986. "The Role of Learning and Coordination in Strength Training." *European Journal of Applied Physiology & Occupational Physiology* 55 (1): 100-105.

Sailors, M. and K. Berg. 1987. "Comparison of Responses to Weight Training in Pubescent Males and Men. / Comparaison Des Reponses a l' Entrainement De Musculation Chez Des Garcons Impuberes Et Des Hommes." *Journal of Sports Medicine & Physical Fitness* 27 (1): 30-37.

Sandercock, Gavin R. H., Matthew J. Taylor, Christine Voss, Ayodele A. Ogunleye, Daniel D. Cohen, and David A. Parry. 2013. "Quantification of the Relative Age Effect in Three Indices of Physical Performance." *Journal of Strength & Conditioning Research* (Lippincott Williams & Wilkins) 27 (12): 3293-3299.

Santos, E. J. and M. A. Janeira. 2012. "The Effects of Resistance Training on Explosive Strength Indicators in Adolescent Basketball Players." *Journal of Strength and Conditioning Research / National Strength & Conditioning Association* 26 (10): 2641-2647.

Schulz, K. F., I. Chalmers, R. J. Hayes, and D. G. Altman. 1995. "Empirical Evidence of Bias. Dimensions of Methodological Quality Associated with Estimates of Treatment Effects in Controlled Trials." *JAMA* : *The Journal of the American Medical Association* 273 (5): 408-412.

Singapore Management University (2014). How do I use Chicago Author-Date Citation Style. Retrieved 11/12, 2013. http://researchguides.smu.edu.sg/chicagostyle

Slinde, Frode, Cathrine Suber, Louise Suber, Cecilia Elam Edwén, and Ulla Svantesson. 2008. "Test—retest Reliability of Three Different Countermovement Jumping Tests." *Journal of Strength & Conditioning Research (Lippincott Williams & Wilkins)* 22 (2): 640-644.

Taylor, Matthew J. D., Daniel Cohen, Christine Voss, and Gavin R. H. Sandercock. 2010. "Vertical Jumping and Leg Power Normative Data for English School Children Aged 10-15 Years." *Journal of Sports Sciences* 28 (8): 867-872.

Temfemo, Abdou, Jullien Hugues, Karen Chardon, Samuel-Honoré Mandengue, and Said Ahmaidi. 2009. "Relationship between Vertical Jumping Performance and Anthropometric Characteristics during Growth in Males and Females." *European Journal of Pediatrics* 168 (4): 457-464.

Toji, Hideki and Masahiro Kaneko. 2004. "Effect of Multiple-Load Training on the Force-Velocity Relationship." *Journal of Strength & Conditioning Research (Allen Press Publishing Services Inc.)* 18 (4): 792-795.

United Nations Programme on Youth. (2013). Frequently asked questions. (Retrieved 10/11, 2013). http://social.un.org/index/Youth/FAQ.aspx

United States Consumer Product Safety Commission. National Electronic Injury Surveillance System. Washington, DC: Directorate for Epidemiology, National Injury Information Clearinghouse, 1987

United States Consumer Product Safety Commission. National Electronic Injury Surveillance System. Washington, DC: Directorate for Epidemiology, National Injury Information Clearinghouse, 1979.

Walker, Simon, Heikki Peltonen, Janne Avela, and Keijo Häkkinen. 2013. "Neuromuscular Fatigue in Young and Older Men using Constant Or Variable Resistance." *European Journal of Applied Physiology* 113 (4): 1069-1079.

Walmsley, R. P., N. Pearson, and P. Stymiest. 1986. "Eccentric Wrist Extensor Contractions and the Force Velocity Relationship in Muscle." *Journal of Orthopaedic and Sports Physical Therapy* 8 (6): 288-293.

Wathen, D. 1993. "Literature Review: Explosive/plyometric Exercises." *National Strength & Conditioning Association Journal* 15 (3): 17-19.

Webber, Sandra 1996. "Neuromechanical Factors Responsible for the Generation of moments about the knee." Master's Thesis., University of Manitoba.

Weltman, A., C. Janney, C. B. Rians, K. Strand, B. Berg, S. Tippitt, J. Wise, B. R. Cahill, and F. I. Katch. 1986. *The Effects of Hydraulic Resistance Strength Training in Pre-Pubertal Males*. Vol. 18.

WinWong, P., K. Chamari, and U. Wisløff. 2010. "Effects of 12-Week on-Field Combined Strength and Power Training on Physical Performance among U-14 Young Soccer Players." *Journal of Strength & Conditioning Research (Lippincott Williams & Wilkins)* 24 (3): 644-652.

Young, W. K. and J. D. Metzl. 2010. "Strength Training for the Young Athlete." *Pediatric Annals* 39 (5): 293-299.

Youth Social Policy and Development Division.". Frequently asked questions. (Retrieved Nov 9, 2013). http://undesadspd.org/Youth/FAQs.aspx

Zady, M.Z., "Z-4: Mean, Standard deviation, and Coefficient of variation". Westgard QC (2009). Last modified 4/20/14. http://www.westgard.com/lesson34.htm

Zaricznyj, B., Robertson, R. V., Shattuck L. J., D'Elia, G. and Mast, T.A. Deerfield Beach, Fla. *Sports Related Injuries in School-Age Children*: Transcripts for Tomorrow, Inc, 1980.

Ziv, Gal and Ronnie Lidor. 2010. "Vertical Jump in Female and Male Basketball players—A Review of Observational and Experimental Studies." *Journal of Science & Medicine in Sport* 13 (3): 332-339.