A COMPARISON OF EIGHT-WEEK RESISTANCE TRAINING PROGRAMS IN ADOLESCENTS

By

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PUBLIC ABSTRACT

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Resistance training has been utilized as a means to improve health outcomes and sports performance in adolescents. This study compared the effects among kettlebells, dumbbells, and non-weight training control groups on changes in muscular strength, muscular endurance, muscular power, percent body fat, running speed, running agility, and flexibility in adolescents. Thirty-five participants (aged 12 to 17 years) completed both pre-test and post-test measures and attended the minimum 70% of the training sessions. All outcomes were assessed prior to the start of the training program and immediately after eight weeks of resistance training and included a three-repetition maximum (3RM) bench press, 3RM leg press, total number of repetitions with 95 pounds, timed single-leg wall sit and summed, body composition, vertical jump, long jump, 40-yard dash, Pro Agility test, and sit-and-reach. There were differences among the three groups after training for the dumbbell group which improved in 3RM bench press and timed single-leg wall sit. This study showed that non-traditional modes of resistance training were not effective at improving health outcomes and sports performance. These modes of resistance training may need longer training durations to see improvements in outcomes.

ABSTRACT

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Resistance training has been shown to improve both health- and skill-related fitness in adolescents. The purpose of this study was to compare the effects among kettlebells, dumbbells, and non-weight training control groups on changes in muscular strength, muscular endurance, muscular power, body composition, running speed, running agility, and flexibility in adolescents. Thirty-five participants (aged 12 to-17 years) completed both pre-test and post-test measures and attended the minimum 70% of the training sessions. All outcomes were assessed prior to the start of the training program and immediately after eight weeks of resistance training and included a three-repetition maximum (3RM) bench press, 3RM leg press, total number of repetitions with 95 pounds, timed single-leg wall sit and summed, BodPod, vertical jump, long jump, 40-yard dash, Pro Agility test, and sit-and-reach. Maturity was assessed using estimated age at peak height velocity. An ANCOVA controlling for the baseline value and maturity showed improvements for the 3RM bench press ($p = 0.018$) and the timed single-leg wall sit ($p = 0.041$). These findings show that improvements occurred only in one mode of resistance training and non-traditional modes of resistance training may need a longer training duration to elicit improvements in outcome variables.

This dissertation is dedicated to my parents, my wife, and my children.
Thank you for always being by my side and believing in me.

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CHAPTER ONE: INTRODUCTION

Approximately one-third of U.S. adolescents are either overweight or obese (Ogden et al, 2014), which is a concern for public health officials (Let's Move; National Collaborative on Childhood Obesity Research). Obesity is associated with a number of cardiovascular risk factors (Willett et al, 1995; Flegal et al, 2005) and metabolic (Colditz et al, 1995; Field et al, 2001) diseases in adults, with some risk factors also prevalent in youth (Freedman et al, 2007). Regular physical activity is an important component in reducing the risk of obesity and other diseases for both adults and youth (USDHHS, 2008).

Specifically for youth, recommendations indicate that children and adolescents need at least 60 minutes of mostly moderate-to-vigorous intensity physical activity daily. At least three of these days should also include muscle and bone strengthening (resistance training) activities (Strong et al, 2005; USDHHS, 2008). Muscle strengthening activities can include various games or resistance training using free weights, body weight, resistance training machines, or resistance bands (USDHHS, 2008).

Resistance training can be used to improve both health-related outcomes and skill-related performance for youth. Examples of health-related outcomes that are positively associated with resistance training are body composition (McGuigan et al, 2009; Sgro et al, 2009; Velez, Golum, & Arent, 2010; Baker et al, 2013), insulin resistance (Bell et al, 2007), blood lipid levels (Fripp & Hodgson, 1987), and muscular strength (Faigenbaum et al, 2005; Chelly et al, 2009). Skill-related performance is the ability to perform a particular sport or activity/skill (Fahey, Insel, & Roth, 2009). Examples of skill-related performance that are positively associated with resistance training are jumping ability (Chelly et al, 2009; Ferrete et al, 2014), agility (Christou et al, 2006; Sekulic et al, 2013), and sprint speed (Chelly et al, 2009). Some studies have documented improvements in both health-related and skill-related performance. For example, Velez et al, found that children and adolescents who engaged in at least eight weeks of resistance training improved in overall body composition and muscular strength (2010). Thus, muscular strengthening activities have been established as beneficial for the overall health and well-being of youth.

National organizations such as the National Strength and Conditioning Association (NSCA), American Academy of Pediatrics (AAP), and the Canadian Society for Exercise Physiology (CSEP) have created recommendations for youth participating in resistance training programs (Council on Sports Medicine and Fitness, 2008; Behm et al, 2008; Faigenbaum et al, 2009). A common characteristic among the recommendations includes a proper warm-up using dynamic and body weight exercises (e.g., hops, skips, and jumps) to gradually increase the body temperature and range of motion in the body joints. Additional recommendations include safety-related components, such as qualified supervision, appropriate progression of exercise intensities and volume, and focus on learning the correct exercise techniques early in the training program (Behm et al, 2008; Faigenbaum et al, 2009). The progression of the exercise intensity and volume should be gradual in order to maximize training benefits and to decrease the risk of injury (Behm et al, 2008; Faigenbaum et al, 2009). If these recommendations are followed, youth are capable of improving in both health- and skill-related variables, with minimal risk of injury (Behm et al, 2008; Faigenbaum et al, 2009).

Resistance training studies have utilized a variety of frequencies, intensities, durations, and types of exercises to evaluate the trainability of youth. However, the ideal combination of these characteristics to benefit overall health and/or performance has not been established in the youth literature. Frequency of training is the number of training sessions per week. In general, children and adolescents with less training experience should train fewer times per week than those with more experience as a way to improve confidence and participation in training programs (Baechle, Earle, & Wathen, 2000). When the child or adolescent has become familiar with the training program, the number of training sessions per week can then be increased. Training frequencies of two non-consecutive days per week with varying intensities have shown improvements in muscular strength, muscular power, and agility (Gorostiaga et al, 1999; Faigenbaum et al, 2002; Faigenbaum et al, 2005; Faigenbaum et al, 2007; Ferrete et al, 2014; Keiner et al, 2014) and body composition (Eather, Morgan, Lubans, 2015) in youth. Three days of training on non-consecutive days also appears to improve muscular strength (Tsolakis, Vagenas, Dessypris, 2004; Velez, Golem, Arent, 2010) as well as body composition (Velez, Golem, Arent, 2010; Dias et al, 2015). Thus, for individuals with limited resistance training experience, two sessions per week appears to be enough to elicit improvements in both health- and performance-related outcomes and can be increased once the individual has become accustomed to the training program. Consensus has not been reached on the ideal number of training sessions per week, but it appears as though two to three times per week is optimal.

Intensity of resistance training is based on the amount of weight that can be lifted for each exercise within the training session (Fahey, Insel, & Roth, 2009). It is typically quantified by any repetition maximum (RM) resistance that is performed within each training session. For example, a ten RM is the maximum amount of weight that can be lifted 10 times, but not 11. Another way to express the intensity of the resistance training session is through a percentage of the individual's 1 RM (Fleck & Kraemer, 2004). Intensity of the resistance exercise is one of the most important variables for developing both health- and skill-related outcomes. When designing an exercise program, the exercise professional must keep in mind how the intensity of the exercises will gradually progress throughout the duration of the training program and must consider the increases in intensity in terms of the participant's capabilities. Researchers have shown that an intensity of 10- to 15- repetition maximum, classified as a moderate intensity, is sufficient to improve muscular strength (Faigenbaum et al, 2002) and muscular power (Chaouachi et al, 2014a) in youth. Varying intensities have been utilized to determine the effects of resistance training on body composition. Using a mixture of repetitions and tempo (pace of the movement) of the training exercises, McGuigan and colleagues (2009) found that a resistance training program was able to produce a decrease in overall body fat as well as an increase in the lean body mass of children. Additionally, in another study, gradually increasing the intensity of the training program from six to eight RM to three to five RM over the course of the study produced improvements in body fat percentage as well as lean body mass (Sgro et al, 2009). Intensity of the training program is dependent on the level of comfort of the individual and must be gradually increased to see improvement in skill-related outcomes (Fleck & Kraemer, 2004), and it is related to outcomes such as muscular strength and muscular power.

Coupled with the number of repetitions performed during each training session is the number of sets the individual will perform. The total number of sets and repetitions comprise the total volume of resistance training the individual performs (Fleck & Kraemer, 2004). In a training study of collegiate tennis players, a periodized training model using multiple sets produced an increase in fat-free mass and a decrease in overall body fat percentage, estimated using skinfold measures, as compared to a one-set circuit resistance training program (Kraemer et al, 2000). In adults, the total number of sets has varied from one set to exhaustion to using multiple sets (Stone, Johnson, & Carter, 1979; Hunter & Culpepper, 1995; Radaelli et al, 2013). In young adults, results of one resistance training program showed no statistical difference between groups performing one versus three sets (all with six repetitions) for muscular strength in the bench press, biceps curl, or shoulder press (Baker et al, 2013). However, when the total training program volumes were compared, participants who completed a high volume program, quantified as three sets per exercise, had the largest improvement in 1-RM testing for the bench press, upright row, and squat exercises, as compared to the group that completed a low volume program, quantified as one set per exercise, and the moderate volume program, quantified as two sets per exercise (Naclerio et al, 2013). Therefore, performing one to three sets of a moderate intensity appears to be sufficient in improving both health- and skill-related outcomes.

One other component of a resistance training program is the duration of training. Experimental studies have utilized either free weight exercises or child sized equipment for a minimum of six weeks (Faigenbaum et al, 2002; Faigenbaum et al, 2005; McGuigan et al, 2009; Sgro et al, 2009). Longer training studies of 12+ weeks have re-tested their participants in regular intervals during the training program and have shown improvements in skill-related outcomes within the first eight weeks of training (Sgro et al, 2009; Moraes et al, 2013; Ferrente et al, 2014). In a 24-week training study, participants were tested at baseline, eight weeks, 16 weeks, and 24 weeks. Improvements in body composition were apparent after eight weeks of consistent resistance training (Sgro et al, 2009). No studies were found that used shorter training durations, so it appears that resistance training programs need at least six to eight weeks in order to induce significant positive changes in health and performance in youth.

Different modes of resistance training equipment are available for an individual to use for the purpose of enhancing health-related and skill-related outcomes. Ballistic exercises, which are characterized by an explosive movement, are beneficial for improving muscular strength and power through increasing the rate of force development (Fleck & Kraemer, 2004), which is important for many aspects of sport performance, including both running and jumping. One particular type of ballistic exercise is Olympic lifting, which typically uses the clean and jerk or snatch exercises with free weights. One important consideration to utilizing Olympic lifting as a training method is the amount of coaching the participant would need, especially for someone who is just beginning to include resistance training as a part of the exercise or sport. The Olympic lifts involve moving a weighted bar from the floor to an overhead position in a short amount of time, so an individual working with the participants would need to spend time prior to starting a training program instructing how to drop a weightlifting bar in a controlled manner as well as how to maneuver the bar, especially when the lift attempt will not be successfully completed (USA Weightlifting, 2001). As the speed of the movement increases, so do the compressive and shear forces produced, which may be difficult for the muscles of a developing child or adolescent to handle (Kielbaso, 2000). Therefore, for individuals who are beginning resistance training, incorporating Olympic lifts may not be appropriate due to many safety concerns.

Traditional resistance training, where the movement of the exercises is more controlled than ballistic exercises, is beneficial for improving both health- and skill-related outcomes. One of the benefits in including traditional resistance training in a comprehensive strength program is the variety of exercises that can be performed. One example of a traditional resistance training exercise includes a squat with resistance, either with free weights or weight machines. Using a back squat training program for eight weeks, Chelly and colleagues (2009) found that adolescent soccer players in the training group improved their squat jump performance and running velocity versus a control group. Researchers have compared Olympic lifting and traditional resistance training and found that Olympic lifting elicited greater improvements in counter-movement jump performance (Chaouachi et al, 2014a). A traditional resistance training exercise, such as a heavy resistance with a squat, has been shown to improve maximal strength with no improvement in rate of force development (Hakkinen, Komi, & Tesch, 1981). However, if there are safety concerns about maintaining proper form throughout the entire lift with a heavy load, a way to teach the proper movements would be to utilize dumbbells, before the participant would move on to heavier loads with a barbell, especially for individuals with little resistance training experience. A wide variety of exercises can be performed with dumbbells, including ballistic exercises. Therefore, including dumbbells in a traditional resistance training program is an appropriate way to introduce resistance training to individuals with little experience, while simultaneously allowing them to experience improvements in health- and skill-related outcomes.

Another mode of resistance training designed to improve strength with ballistic movements is the kettlebell. A kettlebell is a round weight made from steel that resembles a cannonball with a handle attached. Kettlebells were initially used as a device for measuring dry goods at markets and have dated back to early Russia in the 1700's (Kettlebell USA, 2015). Unlike traditional dumbbells, the mass of the kettlebell lies outside of the hands, which makes for ideal use in ballistic and swinging exercises. Within the past 20 years, the kettlebell has gained popularity as a mode of resistance training for improving health- and skill-related performance outcomes (Art of Strength, 2015). In 2012, the International Kettlebell and Fitness Federation held its annual World Competition with 180 competitors (Kettlebell Fitness News, 2012). In 2015, the Championship of Europe was held with approximate 200 participants (World Kettlebell Lifting, 2015). Kettlebells, with their ballistic exercise capabilities, promote engagement of the muscles of the entire body in a coordinated fashion (Viele, 2011). Kettlebells are capable of generating high force outputs (Manocchia et al, 2013), which makes them a viable option in a comprehensive strength and conditioning program for improving muscular strength, power, and cardiovascular endurance (Farrar, Mayhew, & Koch, 2010), as compared to traditional resistance training modes, which can better isolate muscles and/or muscle groups (Viele, 2011). To quantify the muscle activation using a kettlebell, McGill and Marshall (2012) examined two different kettlebell swing exercises and a swing-to-snatch exercise. The gluteal muscles were activated the most in the two swing exercises and were associated with hip extension; whereas the leg muscles were associated with knee extension (McGill & Marshall, 2012), which is an important feature in power development for many different sports. We found no studies which directly compared the muscle activation of the swing to other types of ballistic exercises to know how the kettlebell swing compares. One other important aspect of resistance training is the force that is placed on the spine. Compression forces of the kettlebell swing exercise have been found to be ~2,000 N and shear forces, which are forces acting in opposite directions, have been found to be ~500 N (McGill & Marshall, 2012). No direct comparisons have been made to other resistance training modes; however, during a deadlift, lifting the bar generated up to ~13,000 N in compression forces and ~3,000 N in shear forces in highly trained athletes (Cholewicki, McGill, & Norman, 1991). By producing less compression and shear forces on the spine than other training exercises, it appears as though kettlebells may be a safe option for including in a comprehensive strength training program, which is important for the safety of the developing child or adolescent.

Few training programs using kettlebells exist in the literature, with all of them using adults as study participants. Falatic and colleagues (2015) utilized a four-week training program in collegiate female soccer players. The participants were placed into either a kettlebell training program or a circuit weight-training control group. At the end of the training program, the kettlebell training group had a greater change from pre- to post-test in aerobic capacity than the circuit weight-training group. In an eight-week training study using middle-aged adults, maximal jump height improved in the kettlebell training group, but was not statistically different than the non-exercise control group (Jay et al, 2013). Only one study has utilized kettlebells to determine their efficacy in terms of changing body composition. Otto and colleagues (2012) compared a six-week training program using kettlebells and Olympic lifting and found that neither training group made improvements on overall participant body fatness. However, nutritional intake was not assessed during the length of the study, so appropriate conclusions regarding the efficacy of training on body composition cannot be drawn (Otto et al, 2012). Comparing different training modes is difficult, as many kettlebell training studies have utilized different training loads between the kettlebell and other modes being tested (Otto et al, 2012), so the appropriate conclusions about the efficacy of kettlebell for improving health- and skill-related outcomes cannot be drawn from existing literature. In order to have a true comparison between different modes, the different training programs should match in the overall training load (intensity, sets, and repetitions), as well as the muscles and the training movements (ballistic, controlled, etc.).

In a pilot study for the proposed investigation, we tested the feasibility and efficacy of kettlebell training in 12-15 year-old adolescents. Participants improved in strength (bench press, leg press), long jump, and the 40-yard dash after eight weeks of training. Although these results are based on four participants, it appears that kettlebell training is a viable option for including in a comprehensive strength and conditioning program designed to improve skill-related outcomes. Effect sizes from the pilot study in the kettlebell training group ranged from 0.2-0.3. A recent review by O'Hara and colleagues (2012) considered non-traditional training modes for the use of improving fitness scores of Air Force personnel. The authors of the review found few scientific studies to support the claim of the efficacy of kettlebells for improving work capacity and performance. A recommendation of the authors was to compare kettlebells to other modes of resistance training on run performance (O'Hara et al, 2012).

When considering large groups of adolescents, especially in the middle school and high school ages, the effect of maturation is something to consider, especially for sports that are played during those ages. It is possible for boys and girls of the same chronological age to have differences in health- and skill-related outcomes as a result of the timing and tempo of maturation (Malina, Bouchard, Bar-Or, 2004). Adolescent boys who are advanced in maturity typically show greater pushing strength than boys who are later in maturity as well as various motor tasks, specifically explosive strength, upper body muscular endurance, running speed and agility, and flexibility (Malina, Bouchard, Bar-Or, 2004). Since it is possible to have a wide variation in health- and skill-related outcomes as a result of maturity, it is something to consider when designing resistance training programs for adolescent populations.

Although resistance training in youth is beneficial for health and performance outcomes, further examination of strength training type/mode is necessary to determine the efficacy of resistance training programs on many health- and skill-related outcomes. The overall purpose of this dissertation is to evaluate the effects on health- and skill-related outcomes of an eight-week resistance training program using kettlebells compared to a dumbbell resistance training program and control groups in adolescents. Kettlebells have not been examined for their efficacy to promote gains in health- and skill-related outcomes in adolescents. This training program will utilize common exercises for both kettlebells and dumbbells.

RESEARCH AIMS

Aim 1: To evaluate differences among 8-week kettlebell resistance training, dumbbell resistance training, and control groups on changes in muscular strength, muscular endurance, muscular power, running agility, running speed, and lower back flexibility in 12- to 17-year-old boys, with and without baseline maturity status as a covariate.

Hypothesis 1A: There will be no differences between free-weight resistance training group and kettlebell training group in muscular strength, muscular endurance, muscular power, running agility, running speed, and flexibility from pre- to post-intervention. Both training groups will elicit greater pre- to post-intervention improvements in muscular strength, muscular endurance, muscular power, running agility, running speed, and flexibility when compared to the control group. Controlling for maturity will not affect the results.

Aim 2: To evaluate differences among 8-week kettlebell resistance training, dumbbell resistance training, and control groups on changes in body composition in 12- to 17-year-old boys, with and without protein consumption, fruit consumption, and vegetable consumption, and baseline maturity status as a covariate.

Hypothesis 2: There will be no differences between the free-weight resistance training group and kettlebell training group in body composition from pre- to post-intervention. Both training groups will elicit greater pre- to post-intervention improvements in body composition when compared to the control group. After controlling for maturity and nutrition, significant differences will remain between the two training groups and the control group with no significant difference between the dumbbell and kettlebell group in body composition from pre- to post-intervention.

Aim 3: To perform a program evaluation of the 8-week training program in terms of dose, fidelity, feasibility, and acceptability.

Hypothesis 3: This aim is not hypothesis driven.

CHAPTER TWO: REVIEW OF LITERATURE

INTRODUCTION

This review of literature examines research related to the frequency, intensity, duration, and type of resistance training with respect to muscular strength, power, running speed, agility, flexibility, and body composition of youth. First, a general overview, including recommendations, is discussed. The mechanisms for muscular strength development are discussed, followed by consideration of the frequency, intensity, duration, type of resistance training programs, and maturity for the outcomes of the current study. The safety and risk of injury during resistance training are also discussed. Finally, a summary of the effects of resistance training in youth is provided.

There is an aim by current public health policy to increase the percentage of children and adolescents who regularly engage in muscle strengthening activities (USDHHS, 2008). Muscle strengthening, specifically resistance training, has been shown to have positive effects on body composition (Donges & Duffield, 2012), muscle strength (Hickson, Hidaka, & Foster, 1994), power (Otto et al, 2012), bone health (Winters-Stone et al, 2011), and metabolic health (Bacchi et al, 2012) in adults, with some of these effects shown in children, specifically body composition (Sgro et al, 2009) and muscle strength (Faigenbaum et al, 1999). Therefore, muscle strengthening activities appear to have a positive influence over many health-related outcomes in both adults and children.

Researchers have utilized resistance training as a mode of exercise for weight loss for obese youth. Sgro and colleagues (2009) employed three different durations of resistance training and found that all training groups lost body fat after eight weeks of training (while accounting for nutritional intake in the analyses). Additionally, a significant improvement in body fat percentage was obtained using an eight-week undulating periodization program in overweight and obese youth (McGuigan et al, 2009). It appears as though youth engaging in resistance training obtain benefits in their overall body composition.

Resistance training can have a positive influence over metabolic disorders. Circuit training induced positive changes in insulin sensitivity after eight weeks of training in obese children (Bell et al, 2007). In Latino adolescents, circuit training decreased the training group's fasting insulin by an average of 24% (Davis et al, 2011). Utilizing free weights, a 16-week training program improved insulin sensitivity on overweight Latino adolescent boys (Shaibi et al, 2006). Thus, resistance training may help improve the way the body utilizes insulin in overweight or obese youth.

Childhood and adolescence are critical times for improving bone mineral density. Resistance training will increase bone mineral density in the specific locations stressed by the exercises. Previously, researchers and practitioners thought that children and adolescents should not engage in resistance training. They believed this type of activity contributed to an increased injury risk to and premature closure of growth plates (Faigenbaum et al, 2009). Youth who engaged in Olympic lifting, a specific type of training utilizing free weights, were found to have a greater bone mineral density than age-matched controls at the lumbar spine, greater trochanter, femoral neck, and Ward's triangle (Conroy et al, 1993). In obese children, resistance training significantly increased bone mineral content when compared to the control group after a six-week training program (Yu et al, 2005). Ultimately, resistance training helps improve bone mineral density for many of the high-risk fracture sites at a critical time in the development process, without compromising the growth of the individual. Thus, there is now evidence supporting the bone health benefits of resistance training in children.

Skill-related fitness is another aspect that may be improved through participation in resistance training for children and adolescents. Skill-related fitness is the ability of an individual to perform an actual sport or activity/skill (Fahey, Insel, & Roth, 2009). Not only are improvements seen for muscular strength, endurance, and power, but also improved coordination and other motor performance skills (Brown, Mayhew, & Boleach, 1986). These motor performance outcomes are all important for the overall health of the child as well as performance in sport. Many sports require running various distances with or without change in direction and resistance training is one way to help improve both running speed (Christou et al, 2006; Kotzamanidis, 2006; Tsimahidis et al, 2010) as well as the ability to change direction quickly (Christou et al, 2006; Keiner et al, 2014). Jumping ability has also been shown to improve after resistance training in youth (Christou et al, 2006; Chelly et al, 2009). Thus, resistance training is a beneficial way to improve skill-related fitness outcomes in children and adolescents.

Resistance training exercises should follow recommended guidelines, in order to not cause permanent damage to the health of the child or adolescent and provide the benefits of strength, endurance, or power. Three organizations have recently created guidelines for resistance training in children and adolescents (Behm et al, 2008; Faigenbaum et al, 2009; Lloyd et al, 2013). Common guidelines among the groups state that a dynamic warm-up of 5 to 10 minutes, consisting of exercises that require balance, coordination, and power, should be sufficient to perform the various exercises without risk of injury. For children and adolescents beginning resistance training, the focus should be on light weights with a moderate number of repetitions in order to learn the proper movement and technique of the lifts and gradually increase the resistance as the child becomes accustomed to the movement (Faigenbaum et al, 2009; Behm et al, 2008). However, before a child should initiate a resistance training program, s/he should be aware of the potential risks and be able to handle the physical and mental stress that accompanies resistance training (Faigenbaum et al, 2009). In addition to these recommendations, proper instruction and supervision is required for the child as his/her safety is the most important. Experts recommend that individuals who train children or adolescents have a solid understanding of the youth resistance training guidelines and ability to manipulate the program to fit the needs of the child or adolescent (Behm et al, 2008; Faigenbaum et al, 2009). If a child or adolescent follows these guidelines, resistance training will likely be a safe and enjoyable activity.

OUTCOMES OF RESISTANCE TRAINING STUDIES

Muscular Strength

Muscular strength is the ability of a muscle to generate force, which is one of the primary outcomes of many studies investigating the responses to resistance training. Prior to the 1980s, researchers believed that children could not increase muscular strength from engaging in resistance training exercises, due to the fact that circulating testosterone levels do not increase until the child reaches puberty. However, these studies had the children and adolescents perform resistance training exercises with a very low intensity or volume, which was not sufficient in increasing muscular strength (Komi et al, 1978). In order for the resistance training program to be effective, it must properly overload the muscles by utilizing the proper intensity and volume. Numerous studies have found that utilizing a moderate to high training load will provide a significant increase in muscular strength in pre-adolescent children (Ramsay et al, 1990; Faigenbaum et al, 1996; Faigenbaum et al, 1999; Tsloakis et al, 2004; Faigenbaum et al, 2005). However, these studies used different combinations of intensity, volume, and duration, so it does not appear that the optimal combination has been established. One study in particular compared the strength gains from two different protocols. One group engaged in a low repetition-high load program (i.e., 6-8 repetitions), whereas the other group engaged in a high repetition-moderate load program (i.e., 13-15 repetitions). At the end of the eight-week training protocol, both groups increased in muscular strength compared to the control group, which did not engage in any resistance training exercises. However, the high repetition group increased their muscular strength more than the low repetition group for both the upper-body and lower-body assessments (Faigenbaum et al, 1999). It appears that for youth just beginning a weight training program, using a moderate intensity with higher repetitions can improve muscular strength.

One way to influence the intensity and volume of the training program is through the number of sets performed. In youth, no known studies have compared the number of sets performed, (e.g., one versus two versus three). However, three studies in young adults compared one set to three sets in a resistance training program and did not show a significant difference between the two groups in 1RM bench press, with both groups improving from pre-test to post-test (Rhea et al, 2002; Sooneste et al, 2013; Baker et al, 2013). The 1 RM leg press had a significantly greater positive percent change in the three-set group than the one-set group (Rhea et al, 2002). Authors that conducted a meta-analysis compared three sets to a single set and found a medium effect size favoring three sets (Rhea, Alvar, & Burkett, 2002). Thus, performing three sets of resistance training exercises appears to elicit a greater improvement for muscular strength; although for youth, the influence of the number of sets performed remains unclear because most studies have been conducted with young adults.

Few studies have investigated the frequency of training and its effects on increasing muscular strength and/or hypertrophy in children and adolescents. Using a single set of 10-15 repetitions for exercises with the major muscle groups of the body, Faigenbaum and colleagues

(2002) compared a training frequency of once and twice per week for eight weeks. These authors found that those children who trained twice per week made greater improvements in both 1RM for upper- and lower-body strength as compared to the once per week and non-exercise control groups (Faigenbaum et al, 2002). Other training studies have typically used either two or three times per week of training (Gorostiaga et al, 1999). No studies have directly compared training once, twice, and three times per week. Thus, training twice per week appears to be sufficient in improving muscular strength in youth, but more comparisons of training frequency need to be done in youth.

In order to increase strength that persists in children over time, one of the important components of resistance training program design that must be considered is the duration of the training in the study. When considering children, strength increases have been found in as little as eight weeks (Faigenbaum et al, 1999) with some studies utilizing various training durations from six weeks (Gorostiaga et al, 1999), to 12 weeks (Suman et al, 2001) to 20 weeks (Ramsay et al, 1990) with positive results for muscular strength. The six-week training duration was in adolescent handball players and was during the normal handball season, where one game per week was played (Gorostiaga et al, 1999). The authors postulated that maturational effects may have played a role in the strength development. However, overall it appears that muscular strength can improve in as little as six weeks of training in children and adolescents.

Overall, muscular strength is an important component for skill-related fitness. The literature suggests that resistance training programs of a moderate intensity at least twice per week for a minimum of six weeks provide gains in strength. These training studies have typically utilized either free weight or resistance machines during the training program.

Additional modes of training are currently available and need to be evaluated by comparing the various modes of training.

Muscular Power

Muscular power is defined as the rate of performing work (Kenney, Wilmore, & Costill, 2012). Many different field tests are available to test muscular power in adult and youth populations, including vertical and broad (horizontal) jumps. These tests identify explosive movement of individuals, which is important for many different sports (Martel et al, 2005; Campo et al, 2009) and should reflect the type of activity of the individual. Training studies have utilized various frequencies, intensities, durations, and types of exercises to enhance jumping ability in youth. For youth with limited experience with resistance exercises, training twice per week has been effective in improving both vertical and horizontal jumping ability (Adams et al, 1992; Martel et al, 2005; Faigenbaum et al, 2007; Meylan & Malatesta, 2009; Granacher et al, 2011a). Higher training frequencies per week can be used for youth with more experience with resistance training and have produced improvements in vertical jump height (Matavulj et al, 2001; Ingle, Sleap, & Tolfrey, 2006). Thus, it appears as though training at least twice per week is sufficient to improve muscular power.

Intensities of the resistance training programs have varied in the studies that have examined power outcomes for children and adolescents. Resistance training programs which have utilized training loads at/near maximal strength have shown improvements in vertical jumping ability (Channell & Barfield, 2008). Additionally, training studies that have utilized lighter loads which can be moved quickly have exhibited improvements in jumping ability (Christou et al, 2006; Channell & Barfield, 2008; Chelly et al, 2009; Chaouachi et al, 2014a). Utilizing a single set of resistance exercises, Faigenbaum and colleagues (2005) were not able to elicit any significant change between groups that performed 6-10 RM and 15-20 RM after eight weeks of training. The authors believe the training program may not have been at a sufficient velocity to elicit any changes (Faigenbaum et al, 2005a). An important factor is how the program continually increases in intensity, thus overloading the neuromuscular system and avoiding any plateau in muscular power. As long as the training intensity is gradually progressing throughout the training program, youth seem to improve with a variety of intensities.

Training duration has varied throughout the training studies with the most common duration of training being eight weeks (Faigenbaum et al, 1996; Faigenbaum et al, 1999; Faigenbaum et al, 2002; Channell & Barfield, 2008; Meylan & Malatesta, 2009). A training program in female volleyball players for six weeks improved vertical jump height compared to a control group that used flexibility exercises (Martel et al, 2005). The same effect was shown with basketball (Matavulj et al, 2001) and soccer players (Campo et al, 2009) as well. Eight weeks of training increased the countermovement jump height in soccer (Meylan & Malatesta, 2009) and football players (Channell & Barfield, 2008). Therefore, it appears a minimum of six weeks for the training program is needed for improvements in jumping ability.

Similar to muscular strength, the literature suggests that muscular power can improve with a moderate intensity resistance training program at least twice per week for a minimum of six weeks. Studies have typically used either free weights or machines for the resistance training program; however, other modes are currently available and need to be evaluated for improving muscular power. Within the training program, it appears as long as there is a gradual overload, youth are capable of improving muscular power.

Running Speed

Running speed is a key component for many different sports and can be influenced by an individual's overall muscular strength, which can affect the individual's stride length. Additionally, other factors such as flexibility, stride frequency, and body composition affect running speed. The focus of this section will be on the contribution of muscular strength to running speed. Various distances have been used to evaluate running speed with 30-meters (Kotzamanidis, 2006; Christou et al, 2006; Tsimachidis et al, 2013; Chaouachi et al, 2014b; Meylan et al, 2014a; 2014b) or 40-meters (Shalfawi et al, 2013) the most common. Other running tests have utilized a sport specific protocol. For example, a study with softball players used a one base and two base running protocol (Nimphius, McGuigan, Newton, 2010) or 100-meter sprint (Delecluse et al, 1995). Within each of these sprints, times were recorded for the first 10-meters, as a measure of acceleration (Kotzamanidis, 2006; Christou et al, 2006; Meylan & Malatesta, 2009; Nimphius, McGuigan, Newton, 2010; Meylan et al, 2014a; 2014b). Therefore, when evaluating running speed, the test and/or distance that is chosen should be appropriate for the participants in the study.

Similar to the other performance outcomes, researchers conducting training studies have utilized a variety of training frequencies, intensities, and durations for improving sprint performance. The training frequency most commonly used has been twice per week (Delecluse et al, 1995; Christou et al, 2006; Kotzamanidis, 2006; Tsimahidis et al, 2010; Meylan et al, 2009; 2014b). Training twice per week elicited improvements in sprint time from pre- to post-training (Christou et al, 2006; Kotzamanidis, 2006; Tsimahidis et al, 2010). One training study that utilized a frequency of three days per week elicited improvements in both the 10-meter and 30-meter sprint (Chaouachi et al, 2014b). No studies have compared the effects of training two days and three days per week on running speed in youth, but it appears training twice per week is sufficient to induce improvements in running speed.

The intensity of the training can dictate the improvements that are seen at the end of the training program. Programs that have emphasized a quick velocity and gradually overload the body have improved the sprint times post-training (Delecluse et al, 1995; Christou et al, 2006; Chelly et al, 2009; Chaouachi et al, 2014b). In a training study using 70%-90% of the back squat 1RM, the training program was adjusted at the halfway point during the training program to continually overload the body. This training program elicited improvement from pre- to post-testing in the training group (Chelly et al, 2009). As long as there is a gradual overload of the training program, resistance training appears to be beneficial for improving sprint performance.

The length of a training program has an effect on the improvement of running speed in youth. Training studies have utilized various lengths of training to improve running speed, ranging from eight weeks to 16 weeks. However, no studies have directly compared different durations of the training program to see if there are differences in improving running speed in youth. The running speed during a 30-m run showed significant improvements at the midway point (five weeks) in a 10-week training program (Tsimahidis et al, 2010), with other studies showing improvements in sprint time after eight weeks (Christou et al, 2006; Chelly et al, 2009; Meylan et al, 2009). It appears a training program lasting at least five weeks can make significant improvements in running speed of various lengths.

For a majority sports, running speed is a key component for performance. Engaging in a resistance training program twice per week for a minimum of five weeks appears to be enough to induce an improvement in overall running speed. Other modes of resistance training are available and need to be evaluated for enhancing running speed, as the majority of training studies have utilized either free weights or machines. Additionally, the test and/or distance chosen should reflect the demands of the sport in which the individual participates.

Agility

Agility is characterized as a quick change in direction. Many sports require quick change in directional movements, such as soccer, football, and tennis. Different field tests are available to test the agility of individuals, with a common test being the 5-yard-10-yard-5-yard test (pro agility). Training to enhance the athlete's ability to change direction quickly may lead to more opportunities for scoring and improved one-on-one outcomes (Reilly, Bangsbo, & Franks, 2000). Thus, training the individual's agility is an important component to actual sports performance.

Training programs for improving agility have typically involved training twice or three times per week. The majority of these training studies have had soccer players as their participants (Christou et al, 2006; Meylan et al, 2009; Keiner et al, 2014). A training study by Keiner and colleagues (2014) used a variety of training exercises twice per week in different age cohorts and showed improvement in change of direction as compared to a normal soccer participation group. In adolescent boys, a training program twice per week improved shuttle run time in both training groups (Faigenbaum et al, 2007). Studies that have compared training frequency for improving agility have not been completed. However, it appears as though training twice per week is sufficient for improving youth's agility.

The intensity of the training program has varied for investigating the effects on agility in youth. Training programs have typically utilized one to three sets with varying repetition ranges (Christou et al, 2006; Faigenbaum et al, 2007; Meylan et al, 2009). A training program that gradually increased from 15 repetitions at 55-60% of 1 RM to eight repetitions at 75-80% of 1 RM using two to three sets per training session improved the 10 x 5 m agility run compared to a non-exercise control group (Christou et al, 2006). Keiner et al. (2014) used five sets of a low repetition range and found the strength training groups for all cohorts improved in their agility time compared to youth who were in the soccer control group. However, no studies have compared different training intensities on agility in youth. It appears as though using two to three sets of a low-to-moderate training intensity can improve the agility in youth.

The duration of the training program has varied in resistance training studies for investigating the effects on agility in youth. Training studies have ranged from six to 16 weeks in youth. Training twice per week for six weeks showed greater improvements in the combined (plyometric and resistance training) training group than the regular resistance training group (Faigenbaum et al, 2007). A longer training study of 16 weeks showed agility times improved both at the eight week testing period with further improvements at 16 weeks (Christou et al, 2006). Agility times can improve with training for a minimum duration of six weeks with greater improvements seen in longer training durations.

The overall ability for an individual to change direction in sport is a necessary component in performance. Individuals who engage in a comprehensive resistance training program at least twice per week for six weeks appear to improve their agility. New modes of resistance training are available and need to be evaluated for improving agility, as the majority of the training studies have utilized either free weights or machines. The agility test should also reflect the demand of the sport as well.

Flexibility

Very few researchers have included a description of their flexibility training protocol in youth. However, these studies have included flexibility as one of their outcomes of training. For these studies, it is assumed that static stretching was performed after participation in the training each time, but the frequency, intensity, and duration of stretching is unknown (Faigenbaum et al, 1993; 1996; 2002; 2005; 2007). One study in adults compared the effects of two different stretching protocols on range of motion in the hips (Ciprani, Abel, Pirrwitz, 2003). The flexibility training protocol was performed twice per day with a minimum of four hours between each session. The total volume was equal between the two groups, with the total stretch time equal at one minute. The 10-second stretch elicited a greater improvement in hip range of motion after three and six weeks of training (Ciprani, Abel, Pirrwitz, 2003). In youth, stretching twice for 20-seconds significantly improved sit-and-reach flexibility (Chaouachi et al, 2008). In the training studies that did not describe the flexibility protocol, sit-and-reach flexibility results were mixed (Faigenbaum et al, 1993; 1996; 2002; 2005; 2007). Thus, it appears that greater frequency with shorter durations of stretching leads to an improvement in the joints that are affected by the stretching protocol.

Flexibility is an important outcome which can affect overall performance as well as reducing the risk of developing an injury. It is important to evaluate even if there is not a flexibility training protocol, as training too much may cause an overall muscle imbalance, which may lead to injury. It is difficult to establish recommendations on the amount of flexibility training an individual should perform, since there are few studies that have compared different flexibility protocols. However, holding a particular stretch for at least 20 seconds with greater frequency appears to improve the flexibility of the particular joint.

Body Composition

Resistance training is a type of exercise that may be used to elicit changes in body composition. Training programs targeting the whole-body have shown positive effects on body composition in youth (Yu et al, 2005; McGuigan et al, 2009; Sgro et al, 2009; Velez et al, 2010;

Davis et al, 2011). An eight-week training program in overweight/obese boys and girls elicited significant loss of percent body fat, after controlling for nutritional intake (McGuigan et al, 2009). In young adults, using one set of a high intensity resistance training program produced a greater sum of seven skinfold decrease than the training program using three sets. However, dietary intake was not assessed in the study, so it is unclear whether changes in the dietary behavior also influenced the results (Baker et al, 2013). Yu and colleagues (2005) designed a whole-body training program for obese children which elicited a positive change in body composition in the training group after training three times per week for six weeks. At the end of the six-week training period, children were offered additional training for 28 weeks, once per week. At the end of this program, the training group lost an average body fat percentage of 2.2%, while the control group lost an average of 1.2%. The control group received information about diet from a dietitian. However, in this study, there was not a control group who did not receive any intervention, so results cannot be drawn about the effectiveness of the diet intervention. Additionally, participants were not compliant with the diet intervention (Yu et al, 2005). In Latina adolescents, circuit training twice per week for 16 weeks significantly reduced subcutaneous adipose tissue and waist circumference, compared to the control group (Davis et al, 2011). In a 16-week resistance training study using pneumatic training equipment, obese adolescents improved total and regional body composition from pre-test to post-test, but the magnitude of effect was considered trivial. However, true effects are difficult to determine since nutritional intake was not controlled (Shultz et al, 2015). In one of the longest studies, a six-month resistance training intervention using a combination of free weights and machines was not able to produce a significant change in body composition. Dietary intake was not assessed during the intervention, so it is unclear whether there were changes in dietary behavior from pre-test to post-test (Schranz et al, 2014). Thus, when dietary intake is accounted for, resistance training appears to be an effective way to have a beneficial change in overall body composition.

Mode of Resistance Training

The type of exercises that are included in the program may have a potential role in the development of muscular strength in children and adolescents. Currently, there are various types of exercise equipment that could potentially be available for children and adolescents to use, including their own body weight, free weights, nautilus, and elastic tubing, among others. These items could all be utilized in a well-planned exercise prescription with the appropriate progressions and overload systems that are based upon the specifics of the child or adolescent (i.e., age, sex, familiarity with resistance training, etc.). In a review by Myer and Wall (2006), the authors provide guidelines for physicians making recommendations about resistance training to parents and coaches. In comparing multiple modes of resistance training, they state there is no single mode that provides the greatest benefit to performance outcomes and can be used in combination to obtain the performance benefits, while increasing the variety of exercises that is available to the individual (Myer & Wall, 2006). Researchers have utilized a wide variety of exercise equipment, mostly free weights (Ramsay et al, 1990; Christou et al, 2006; Chelly et al, 2009) or machines (Docherty, Wenger, & Collis, 1987; Faigenbaum et al, 2002) in youth.

Few studies have compared training modes. In adolescents, researchers compared a free weight training program to an elastic tubing training program and found that improvements were larger for the free weight group in upper body strength, but similar in lower body strength for boys. Girls had larger improvements for lower body in the free weight training group. In order to keep the intensity of the training groups similar, the researchers instructed the participants on how to use the ratings of perceived exertion (RPE) scale and to have an RPE score between 15-

18 for each set (Lubans et al, 2010). In underweight and obese women, a training program utilized free weight bench press, supine vertical bench press machine, or horizontal bench press machine with similar linear periodization, three times per week for 12 weeks. At the end of the training, general strength gains were not significantly different among the three training modes (Mayhew et al, 2010). In adult males, a strongman training program, which utilized functional exercises, was compared to a traditional training program with moderate to strong effect sizes favoring the traditional training group in 1RM testing (Winwood et al, 2015). When comparing different modes, it is important to consider the overall volume between the modes. If the modes are different in their overall volume, one group is receiving a larger stimulus for muscle growth than the other, which does not allow for a direct comparison between the groups. Additionally, the training programs of the different modes should be as similar as possible with respect to muscle groups and their actions. By making the exercises similar with equal volume, the researcher is able to make a direct comparison of the results from the different modes of training. Thus, it is difficult to determine if there is one particular mode of training that elicits the greatest improvement in performance outcomes since there is very little comparison between modes in youth.

When using free weights, the velocity of the movement can be varied by the individual. Olympic lifting, which incorporates explosive, high-velocity movements throughout the various exercises, has been utilized in highly trained populations (Channell & Barfield, 2008). Channell and Barfield (2008) compared an Olympic lifting group to a power lifting group after eight weeks of training and found that while both groups improved in the vertical jump, those in the Olympic lifting group elicited a 56% greater improvement than the power lifting group. Thus, exercises that emphasize a high velocity appear to elicit greater improvements in skill-related outcomes.

One type of training equipment that is growing in popularity without much research on its effectiveness in promoting gains in health- and skill-related outcomes in adults, adolescents, and children is kettlebells. The design of the kettlebell is set up for ballistic movements, with the round cannonball at the bottom with the handle attached at the top. These have been dated back to the 1700's in Russia and were used as a way to measure dry goods at markets (Kettlebell USA, 2015). Of the few kettlebell training studies that have been performed, the majority have utilized adults as the study subjects. Many of the same types of exercises that can be performed with traditional free weights, as well as machines, can be performed using kettlebells. However, one exercise that is difficult to perform with those pieces of equipment and is a foundation exercise with kettlebells is the kettlebell swing. The kettlebell swing was found to be effective in improving jump height in young males after 6 weeks of training, but was not statistically different when compared with the jump training group (Lake & Lauder, 2012a). Jump height also improved from pre- to post-test in middle-aged adults, but was not statistically different than the non-training group (Jay et al, 2013). In addition to improving jump height, kettlebell training has also been shown to elicit a heart rate response of approximately 85% of heart rate max for young adults and a VO_2 response of 65% of VO_{2max} in young adults (Farrar, Mayhew, & Koch, 2010). In female collegiate soccer players, after four weeks of training, the kettlebell training group had a significant improvement in aerobic capacity than the circuit training group (Faltic et al, 2015). Although jump height has been shown to improve with kettlebells, the peak force and peak power from using kettlebells during a kettlebell swing was much less than using a back squat or jump squat (Lake & Lauder, 2012b). Incorporating the kettlebell swing into a comprehensive kettlebell training program as a cornerstone exercise may elicit gains in strength and power when using weightlifting and powerlifting activities in adults (Manocchia et al, 2013; Otto et al, 2012). However, when a kettlebell training program was compared to a comprehensive resistance training program in young adults, researchers found that the resistance training program elicited greater improvements in weightlifting and powerlifting activities than the kettlebell group (Otto et al, 2012). Compression and shear forces have been found to be lower from kettlebell swings (McGill & Marshall, 2012) than a traditional deadlift exercise (Cholewicki, McGill, & Norman, 1991), although these two exercises were not directly compared. The kettlebell swing also activates the gluteal muscles, which are important in lower body strength and power (McGill & Marshall, 2012). It appears as though kettlebells may improve muscular strength and power in adults, but with no published studies in children and adolescents, it is unclear if kettlebells may be able to provide the same stimulus for improvement.

The order of the exercises may have a role in the development of muscular strength in youth. However, no studies to the author's knowledge exist that have investigated this concept. Although there are no studies to confirm, it is common practice to start with the larger muscle groups and then move on to the smaller muscle groups in a training program (Fleck & Kraemer, 2004).

In addition to the order of exercise and the sets and repetitions, the rest interval may also affect the development of muscular strength. Longer rest periods of two to five minutes are typically used when children are learning various lifts or heavier loads are utilized (Fleck and Kraemer, 2004). For those children or adolescents who have prior experience with resistance training, it is possible to shorten the rest interval in order to properly overload the muscles.

Additionally, a recent study by Bottaro and colleagues (2011) compared the effects of rest intervals in children and adolescents and found that by the third set of exercises, the children recovered faster than the adolescents. Within the adolescents, there was less fatigue with 120 seconds of rest than with only 60 seconds (Bottaro et al, 2011). Thus, performance appears to be sustained with 60-120 seconds of rest.

Assessment of Muscular Strength

When considering whether improvements occur as a result of the resistance training program, accurate assessment of strength and power are necessary, and many methods are used, including repetition maximums, usually one-repetition maximum (1RM), dynamometry for muscular strength, and vertical jump for power. Many of the training programs have been based on the 1RM results for that specific muscle group. For example, in the study by Gorostiaga and colleagues (1999), the initial training load was performed with 40% and increased to 50% of each subject's 1RM. When this is performed, it allows the subject to appropriately overload the muscles and allows for specificity of repeated testing, since a majority of the exercises should be similar to the type of 1RM test. However, it is a necessity that the chosen tests are valid. One study that investigated the validity of the 1RM measure for lower body strength compared it to dynamometry and found that both methods were highly correlated, indicating that the 1RM was a valid measure of muscular strength (Verdijk et al, 2009). However, this study was conducted in adults, and no studies have investigated the validity of the 1RM in children or adolescents to the author's knowledge. Prior researchers have used a 1RM test in order to evaluate the effects of the training program (Faigenbaum et al, 1999; Baker et al, 2013; Schranz et al, 2014). It appears as though in children who have experience with resistance training, 1RM testing is appropriate if the proper protocols are followed and under direct supervision.

Process Evaluation

Researchers should evaluate a training program/intervention in order to determine whether it was successfully implemented. Many researchers report the attendance during the resistance training intervention, but few report a full evaluation, including, reach, dose received, fidelity, feasibility, and acceptability. Lubans and colleagues (2010) reported a full evaluation of their free weight and resistance band training comparison. The participants enjoyed the training programs at the end of the study and attended approximately 75% of the training sessions. Additionally, boys attended more training sessions than girls (Lubans, Sheaman, Callister, 2010). Other authors have only reported the attendance of the training sessions, which have ranged from 90+% (Faigenbaum et al, 1996; Faigenbaum et al, 2005; Granacher et al, 2011a) to 100% (Faigenbaum et al, 2002). Gorostiaga and colleagues (1999) reported the average number of training sessions during the six-week intervention was 11. No studies to the author's knowledge have performed a process evaluation, with respect to the dose delivered or fidelity. In order to establish whether the intervention was successful, it is necessary to examine the intervention through a formal evaluation.

POTENTIAL MECHANISMS OF STRENGTH INCREASES

There are multiple factors that are thought to be potential mechanisms for the observed increases in muscular strength with resistance training in children and adolescents. A primary factor in the development of muscular strength in children and adolescents is the fiber composition of the muscles. Fast twitch muscle fibers (Type II) have more capacity for generating strength and power than slow twitch (Type I) fibers. Infants are born with an approximate 50/50 split between fast twitch and slow twitch muscle fibers (Dubowitz, 1965), which is consistent with older children and adult muscle. However, in child and adolescent soccer players, it was found that the older soccer players had a greater relative percentage of type IIA fibers in comparison to the youngest group by 18.1%, which may have been influenced by adaptations from training (Metaxas et al, 2014). Not only does the fiber type distribution impact the strength development, but the angle of pennation of the muscle fibers may also impact the development of muscular strength in children and adolescents. Pennation angle has been found to be related to hypertrophy of the muscle fibers in adults, and many researchers have investigated the change in muscle size as it relates to the development of muscular strength in children and adolescents. Multiple studies have found that with an increased amount of resistance training, children are not able to increase the cross-sectional area of the muscle fiber (Ramsay et al, 1990; Weltman et al, 1986); however, there is some evidence that the angle of pennation of the muscle fiber may change as the muscle contracts (MacIntosh, BR, Gardiner, PF, & McComas, AJ, 2006; Debernard et al, 2011a). Additionally, as an individual ages it appears the fascicle angle of the muscle fibers changes, which can influence outcomes related to muscular strength (Debernard et al, 2011a). Therefore, the type and angle of the muscle fibers may have a direct influence on the shortening capacity of the muscle fibers, thus affecting health- and skill-related outcomes.

Cross-sectional area (CSA) also may influence the development of strength not only in adults, but also children and adolescents. Various techniques have been utilized to determine CSA including ultrasound, muscle biopsy, and magnetic resonance imaging. Few studies investigating the relationship between CSA and muscular strength have been undertaken in healthy populations. It appears as if children and adolescents with a larger muscle CSA have larger muscular strength values than children or adolescents with smaller muscle CSA (Kanehisa et al, 1994; Hoshikawa et al, 2012; Pitcher et al, 2012; Metaxas et al, 2014). Athletic populations of children and adolescent males playing soccer were found to have a larger CSA of the psoas major when compared to non-athletes that were age-matched (14.4 ± 0.2 cm^2 vs. 13.4 ± 0.3 cm^2, respectively). However, these two groups did not significantly differ in hip flexion force (488.6 ± 9.9 N vs. 465.6 ± 13.3 N, respectively). Although there were no differences between the groups with the hip flexion force, researchers found a positive relationship between hip flexion force and fat-free mass in both groups separately (Hoshikawa et al, 2012). Another study used muscle biopsy to determine the relationship between muscle CSA and muscle strength of the knee flexors and extensors in child and adolescent soccer players. The oldest group of soccer players had the largest CSA of all the muscle fiber types in the vastus lateralis. The oldest group also produced the greatest amount of force compared to the youngest group. Maturational level was accounted for and all participants in each of the groups were of the same maturational level (Metaxas et al, 2014). Thus, it appears the cross-sectional area of the muscle has a role in the overall strength of the individual.

In addition to the type of muscle fiber that is utilized in the exercise, the mechanics of the skeletal muscle contraction also play a role in a muscle's development of force. Specifically, the length-tension relationship and the force-velocity curve of skeletal muscle may have a role in muscular strength. As the length of the muscle increases, the force the muscle is able to produce increases up to a certain point then will decline. This is due to the sarcomere length and the optimal overlap between the myofilaments (MacIntosh, Gardiner, & McComas, 2006). Additionally, the rate of force will affect the development of muscular strength. As a greater load is imposed on the muscle, both the rate of shortening and the amount of shortening are decreased, due to the recruitment of fast twitch muscle fibers and motor neurons as well as an increased firing rate of the motor neurons (MacIntosh, Gardiner, & McComas, 2006). It is difficult to determine if the recruitment or firing rate is more important in the development of muscular strength. It appears as though the recruitment and rate of firing differ between muscles. Adrian and Bronk (1929) concluded that recruitment was more important at low forces, while rate of firing was important for maximal force. Thus, the motor unit as well as the length of the skeletal muscle it innervates will dictate the overall force production.

One of the major factors that may drive the increase in muscular strength in children and adolescents is neuromuscular activity in the absence of muscle hypertrophy. When considering neuromuscular activity, there are multiple components within this topic that may positively affect muscular strength development. Currently, there have been very few studies that have investigated the contributions of neurologic activity to strength training gains in children and adolescents. Many of the studies that have investigated this relationship have included adults, particularly males. The method of neurologic assessment has varied in many of the studies, from direct measurement using a twitch interpolation technique or integrated electromyographic activity to assess the degree of motor unit activation to inferring neurological performance, many times through performance tasks, which has been based upon the lack of evidence for muscle hypertrophy in pre-adolescents. Thus, there is a need to have more studies that utilize a direct measurement to obtain quantifiable measurements to increase the knowledge about the contribution of neuromuscular activity to muscular strength in youth.

The electromyographic (EMG) signal is a combination of the recruitment of motor units, their firing frequency, and the synchronization of the impulses. EMG increases with strength training have been found in adults under a variety of conditions with multiple types of techniques (Hakkinen, Alen, & Komi, 1985; Hakkinen & Komi, 1986; Linnamo et al, 2000). A recent study investigated the neuromuscular difference between endurance trained boys and men with men exhibiting greater overall strength, in addition to the various components of EMG activity (Cohen et al, 2010). Both trained and control men exhibited greater strength and greater EMG activity when compared with the boys. When specifically looking at the differences between the two groups of children, the training group had a greater absolute peak torque than controls, but when this was normalized to body mass, there was no longer a difference. Additionally, there were no differences between the two groups of children in terms of rate of torque development (RTD), rate of muscle activation (Q_{30}), electromechanical delay (EMD), time to peak torque, and time to peak RTD (Cohen et al, 2010). Similar results were found when researchers examined the child-adult differences in elbow flexion and extension (Falk et al, 2009; Dotan et al, 2013). Results were corrected for muscle cross-sectional area (CSA); however, the CSA was derived by using anthropometric techniques instead of more precise measures, such as magnetic resonance imaging (MRI). These lower values of children could be a reflection of the smaller muscle size in children, since they have a smaller potential for shortening (Dotan et al, 2012). In women, while there was no improvement in the maximal isometric elbow flexion torque after resistance training, improvements were seen in the rate of torque development (Gabriel, Basford, & An, 2001). Additionally, lack of musculo-tendinous stiffness of children can also compromise the development of force, since it is more elastic than adults (Kubo et al, 2001; Lambertz et al, 2003; Grosset et al, 2007). In a 10-week resistance training program that utilized calf raises to study the Achilles tendon properties, investigators found that the training significantly increased the tendon stiffness. Rate of force development and EMD were not altered after the resistance training program, which may have an impact on the development of force and strength (Waugh et al, 2014). Additional strength increases and EMG activity have been shown in both boys and girls after 8 weeks of training (Ozmun, Mikesky, & Surburg, 1994), in the vastus lateralis and vastus medialis muscles in adolescent males (Hakkinen, Mero, & Kauhanen, 1989) and in the rectus femoris muscle in adolescent males and females (Komi et al, 1978). It appears as if children and adolescents may not fully recruit the muscle fiber types and motor units that are responsible for generating high forces since their values are lower than adults due to differences in muscle size; however, resistance training may improve children and adolescent EMG activity, which may have an impact in developing muscular strength and activities of daily living, but not enough to reach adult levels.

One other component of neuromuscular activation that may be responsible for increases in muscular strength during childhood and adolescence is improved motor coordination. The tests of neuromuscular activation utilize isolated, single-joint exercise, which may not capture the true effect of the training program, which utilizes complex, multi-joint exercises, on the neuromuscular system. However, it is currently very difficult to separate the various components of neuromuscular activation which might be responsible for the increased muscular strength in children and adolescents, and it is difficult to obtain measures, since the best method is invasive and might be considered inappropriate for children and adolescents.

Muscular stiffness, which describes the relationship between the force being applied and the muscle-tendon length, can impact the gains in muscular strength as a result of a resistance training program and has been investigated in adults, with a few studies in children and adolescents. Muscles with greater amounts of stiffness are able to develop higher amounts of force during a particular movement (McGinnis, 2013). This can have an impact on dynamic movements, such as speed, as well as stability. In young adult rugby players, muscular stiffness had small negative correlations to horizontal and vertical jump forces. This result conflicts with prior research (Bojsen-Moller et al, 2005; Hughes & Watkins, 2008) that stiff muscles have a positive relationship with force output, but the authors did not attempt to explain why this result may have occurred (Dobbs et al, 2015). Using magnetic resonance elastography, Debernard and colleagues (2011b) measured the shear modulus of the vastus medialis in children, young adults, and middle-aged adults. Children showed a lower shear modulus than both the adult groups at rest, which indicated the muscle structure was different between the children and adults (Debernard et al, 2011a). Similar results were found by Lambertz and colleagues (2003) which compared pre-pubertal children and adults. Thus, muscular stiffness appears to increase with age, and ultimately has a positive effect on overall force production.

One other potential mechanism for the development of muscular strength during childhood and adolescence is the amount of circulating hormones in the body. Pre-adolescent children lack some circulating hormones, specifically androgens and testosterone. As a result, children do not undergo muscle hypertrophy, unlike what is seen in adult strength training studies, after engaging in resistance training exercise. In these studies where hypertrophy does not occur, researchers have speculated that the reason for the strength increases is increased neuromuscular activation. The specific hormones that are usually investigated in these studies include insulin-like growth factor-1 (IGF-1), growth hormone (GH), and testosterone. Physical activity interventions with older adolescents have not shown hormone levels of interest changing as a result of the intervention (Eliakim et al, 1998; Gorostiaga et al, 1999). One study compared the effects of a training group to a non-training control group, and researchers found there was no change in the GH and testosterone levels in either group over the course of the intervention, but IGF-1 levels decreased in the training group. However, as a result of training, the thigh muscle volume of the training group increased in size, with no change in the control group. The authors did not have a clear explanation as to why these results occurred; however, they speculated that neuroendocrine mechanisms may have had some role in the outcomes rather than the local muscle or other tissue responses as a result of the exercise (Eliakim et al, 1998). Additionally, resistance training for six weeks did not change the level of circulating hormones in adolescent males (Gorostiaga et al, 1999). However, muscular strength measures have shown a positive association with hormone levels, specifically testosterone, in early adolescent boys (Hansen et al, 1999). Not only can hormones affect the development of muscular strength in children and adolescents, but the type and volume of resistance training may also affect the hormonal response in those individuals. A study by Pullinen and colleagues (2002) investigated the hormonal response, particularly testosterone, GH and catecholamines, during a resistance exercise training session in men, women, and adolescent boys. As a result of the training load, which was 40% of the individual's one repetition maximum for a bi-lateral knee extension-flexion movement, there were no significant increases in testosterone or growth hormone for the adolescent boys. However, the study only included six subjects of each for the men, women, and adolescent boys, so statistical power was lacking (Pullinen et al, 2002). This study may show that a low volume of work may not elicit the hormone response for those particular hormones. The response of GH is linearly dependent on the exercise intensity and that intensity will vary between each individual child or adolescent (Rowland, 2005). Heavy resistance training (i.e., 80-90% 1RM) did not seem to produce an effect in the blood testosterone concentration in adolescent handball players (Gorostiaga et al, 1999). These authors could not provide concrete answers as to the mechanisms that caused this response, with their only potential explanation being that the strength training group may have been overtrained, which might overwork the nervous and endocrine systems. Thus, it appears that GH and testosterone are important for the development of muscular strength and there may be a narrow range of intensity in the resistance training program that can affect the hormone response.

One other component that must be accounted for when considering resistance training studies in adolescents is maturational level, which can impact how much strength is gained. Considering that the adolescent's body is going through changes at varying times, two adolescents could respond very differently to the same training program. When considering maturation in the results of pre-adolescent and adolescent children, changes in strength may be shown as either relative or absolute strength. Comparing pre-adolescent, adolescent, and adult males, maximal isometric strength of the forearm flexors significantly increased from childhood to adulthood, in addition to muscle size. Muscle size, measured with MRI, was also significantly different between pre-adolescents, adolescents, and adults (Tonson et al, 2008). Katzmarzyk and colleagues (1997) found that maturity, calculated using the skeletal maturity of the hand-wrist, was significantly associated with strength and motor performance variables. Pushing strength, which is what is necessary for 1RM testing, appears to increase with age in boys (Malina, Bouchard, Bar-Or, 2004). After an 8-week training program, small to moderate effect sizes were found for adolescents pre-, mid-, and post-peak height velocity (Meylan et al, 2014b). A recent review of literature suggests that individuals who work or train youth should consider the development of the child/adolescent before starting the training program (Lloyd et al, 2014). However, after a 12-week training program, there were no differences by maturational stage in both boys and girls for anthropometric and motor performance variables (Lillegard et al, 1997). Thus, despite some conflict in the literature, maturational status is an important component in evaluating the effects of a resistance training program.

Boys and girls will respond differently to resistance training exercises and in developing muscular strength and power. At younger ages, boys and girls have similar measures of strength and power, with boys typically performing better than girls at all ages (Malina, Bouchard, Bar-Or, 2004). During adolescence, boys gain more muscle mass than females, which increases the strength differences between the sexes (Malina, Bouchard, Bar-Or, 2004). When considering performance outcomes, boys performed better than girls in the 20-m and 30-m sprint, as well as the change of direction. No differences were found in lower body power, after controlling for maturity (Meylan et al, 2014a). Thus, the particular age during the training program will influence the overall performance differences between the sexes. Many researchers combat this by creating sex-specific interventions.

There is not much that is currently known regarding the mechanisms that cause an increase in muscular strength in children and adolescents as a result of resistance training. One study that included controlled for age at peak height velocity showed that two different training programs elicited the similar improvements in muscular strength, muscular power, and speed. However, a non-weight training control group was not included, so the comparability to the normal pattern of growth cannot be determined (Pichardo et al, 2019). Many of the methods for measuring these components are not considered appropriate for this particular population, due to their invasive nature, and more information is needed to fully understand how strength develops in youth.

RISK OF INJURY

Children and adolescents are able to obtain benefits of muscular strength, endurance, and power. As a result of participating in a resistance training program, there is a reduced risk of injury from sports participation (Myer et al., 2005). However, some injuries still occur as a result of the training program itself, as well as during sports participation. For example, a supervised 14-week resistance training program had one injury specifically related to the resistance training program and was resolved with rest for one week (Rians et al, 1987). Training programs that incorporated plyometric exercises and the appropriate coaching of these exercises along with resistance training exercises have improved movement biomechanics (Myer et al, 2006) or reduced the severity of injury (Cahill & Griffith, 1978; Heidt et al, 2000). If the training program or team is supervised by strength and conditioning professionals who encourage a proper warm-up, correct exercise technique, and correct progression of resistance, these injuries could potentially be avoided (Fleck and Kraemer, 2004; Faigenbaum et al, 2009). A cluster randomized controlled trial utilized a warm-up program before participation in a sporting event and found that those adolescents who participated in the warm-up program had fewer injuries during the sport season than those who did not participate in the warm-up program (Olsen et al, 2005).The rate of injury from causes related to resistance training has been found to be lower than injuries from football (Hamill, 1994), which has caused the most injuries over a 1-year period. As a result, it appears as though participation in a resistance training program for children and adolescents is beneficial for their overall health with no greater risk that some common contact sports, and it may reduce the risk of becoming injured as a result of participating in a sporting activity.

OVERALL SUMMARY

As more children and adolescents engage in resistance training, there will be a greater need for accurate and reliable information to create exercise programs within the schools and for the individual. Performance outcomes, most notably strength and power, are affected by multiple mechanisms. These mechanisms are not fully understood and need further investigation, primarily due to beliefs that are no longer true. Until youth reach puberty, increases in muscular strength have been thought to be a result in increased neuromuscular activity. Once puberty is reached, hormone secretion is thought to influence muscular strength through affecting the muscle fibers, as well as neuromuscular activity. These mechanisms ultimately have a combined effect on performance, and more information is needed on the effects of a resistance training program.

Since there is a low risk of injury due to participation in resistance training, youth obtain health and performance benefits by including resistance training activities in their lives. Traditionally, resistance training studies have used a wide variety of frequencies, intensities, durations, and types. When designing the training program, the intensity must be gradually increased through the duration of the training program, with a moderate intensity appropriate for both beginning and advanced weightlifters. Ballistic exercises, specifically kettlebells, have not been investigated much in the youth population. Thus, it is important to compare kettlebells to a traditional resistance training program to determine whether they can be another mode of training that can be utilized by strength and conditioning professionals for inclusion into a comprehensive strength and conditioning program.

CHAPTER THREE: METHODS

OVERVIEW

An 8-week resistance training program using kettlebells or dumbbells was evaluated for effects on muscular strength, muscular endurance, body composition, power, running agility, and flexibility. Participants were randomized into three groups, a kettlebell program, a dumbbell program, and a non-resistance training control group. The measures were assessed at baseline and eight weeks. The training program and data collection for outcome measures took place within IM Sports Circle on the campus of Michigan State University. IRB approval was obtained, as well as informed parent/guardian consent and participant assent.

PARTICIPANTS AND RECRUITMENT

Initially, 15-17 year-old participants were recruited for the study. After a few months of difficulty obtaining participants, the age range was broadened to 12-17 years. Older adolescents had too many time commitments involving school, daily sports practices, other extracurricular activities, and work and could not devote time in their schedules for an eight-week intervention. Forty-nine male adolescent participants were recruited from the city and surrounding areas of East Lansing, Michigan (see power analysis section to follow), and were randomized into one of three groups: a kettlebell training group, a dumbbell training group, and a non-resistance training control group. In order to limit confounding variables, inclusion criteria were restricted to one sex (male). Additionally, results from a pilot study including both sexes showed that the majority of the participants were males who had previously played sports. Participants were recruited from local sports clubs and coaches, health clubs, and recreation centers using flyers and word of mouth. Recruitment emails were sent to MSU faculty and staff through a college-wide and parent list serv. Informed consent and child assent were collected during an introductory session to the resistance training program. Remaining inclusion criteria dictated that participants were between the ages of 12 and 17 years with a minimum of one month of experience with resistance training. Participants also had to have prior sport participation within the previous year and were allowed to participate if they were currently playing a sport. Participants were able to engage in their normal physical education classes during participation in the study. In order to be included in the analysis, participants were required to attend at least 70% of the training sessions (set a priori). One exclusion criterion was any bone, joint, metabolic, or pulmonary condition that could be made worse by participating in an exercise program. Additionally, participants were excluded if they were currently participating in a resistance training program. In order to determine whether the participants were healthy enough to participate in the training program, parents or guardians of the participants were required to fill out a pre-participation health questionnaire to screen for any bone, joint, metabolic, pulmonary, or cardiovascular condition. Participants were excluded if the parent or guardian answered 'yes' to two questions on the health questionnaire. The specific questions were, "Does your child have any chronic disability or chronic illness?" and "Are you aware of any medical reason/condition that might prevent your child from participation in an exercise program?"

MEASURES

Tests of Health-Related Fitness

Muscular Strength

Each participant attended one familiarization session for the testing protocol prior to data collection. The maximal values were found in one testing session. A three-repetition maximum (3RM) was used for both upper and lower body muscular strength and were tested separately. Upper body strength was tested using the bench press using free weights, while lower body strength was tested using a horizontal leg press. Prior to the assessments, all participants were instructed on proper form. A warm-up of 10-repetition maximum was used as a starting point. Gradually, weight was increased by approximately 5-10% until the 3RM was established. For each lift attempt, a recovery period of 1 to 3 minutes was allowed. Intraclass correlations (ICC) from the pilot study were calculated for the bench press (R=0.98) and the leg press (R=0.78).

Muscular Endurance

For upper-body endurance, the maximum number of repetitions that could be performed using 95 pounds was performed until the participant reaches volitional fatigue. For lower-body endurance, a wall-squat test was performed. Each participant started with his back against a flat wall with his knees and hips at a 90-degree angle. When the test started, the participant lifted his foot off of the ground five cm. The test ended when the foot hit the ground. The total amount of time from lifting the foot off to the foot touching was recorded. Each leg was tested twice with the best time from each leg summed and used as a dependent variable.

Percent Body Fat

Body composition (body fat percentage) was assessed using air plethysmography (BodPod) (CosMed USA Inc. Concord, CA). Participants were measured while wearing swimsuits. All manufacturer instructions regarding procedures of measurement were followed. The participants were required to sit in the BodPod chamber and remain still for approximately 50 seconds. Up to three trials were assessed with the BodPod.

<u>*Tests of Skill-Related Fitness*</u>

Vertical Jump

Vertical jump (VJ) was assessed using a Vertec jump trainer (Sports Imports, Columbus, OH). Standing height was measured as the height from the tip of the fingers during an overhead reach to the floor and was measured to the nearest 0.5 inch while the participant walked through the jump trainer. Vertical jump displacement was recorded as the difference between the maximal jump reach and the standing height reach. Participants were instructed to keep their feet shoulder width apart. For the vertical jump, a counter-movement was allowed where the participant started in the standing position and lower to a semi-squat position, and then immediately jump, to take advantage of the stretch shortening cycle. An arm swing was allowed to help maximize vertical jump height. Three trials were attempted with a 30 second rest period between each attempt with the average of the three jumps being retained as the test score. Peak power output was estimated using a regression equation from Quagliarella et al (2011) using the average of the three jumps. The regression equation was specific for the adolescents' ages. For adolescents 12 years of age: -1,069 + (45.9 x BM [body mass]) + (45.4 x VJ [vertical jump] height). For adolescents 13-14 years of age: -1,691 + (47.8 x BM [body mass]) + (72.7 x VJ [vertical jump] height). For adolescent 15-17 years of age: -661 + (47.8 x BM [body mass]) + (39.4 x VJ [vertical jump] height). Reliability of the counter-movement jump has been shown to be 0.98 (Markovic et al, 2004).

Standing Long Jump

Each participant completed three trials with a 30-second recovery between trials. From a standing position, with the feet shoulder-width apart and hands placed directly in front of the body, participants produced a countermovement, where they were able to take advantage of the stretch shortening cycle, before jumping horizontally as far as possible. In order for the jump to count, participants could not touch the ground with any part of the body to help maintain balance. If this occured, then the participant repeated the jump. The greatest distance, in meters (measured to the nearest 0.001 m), of the 3 jumps was used as the test score, with the distance measured from the heel of the rear foot. An acceptable ICC (R=0.93) was calculated from the pilot study.

Running Speed

A 40-yard dash was used to evaluate running speed. Each participant completed three trials with one minute of rest between trials. The test took place in the gymnasium located in IM Sports Circle. Participants were instructed to complete the distance in the shortest time possible. Time was recorded to the nearest 0.01 second by hand using a stopwatch, and many participants were assessed with additional assistance of an electric timing system (Brower Timing Systems, Draper, UT). The timing system had to be returned to the Athletic Department, so 15 participants did not run with the timing system. The timing gates marked the beginning and the end of the run distance for the participants. Regardless, since all times were recorded by hand with a stopwatch, actual timing mechanism was the same for all participants. The fastest time was used as the test score. An acceptable ICC (R=0.92) was calculated from the pilot study.

Flexibility

Lower back and hamstring flexibility was evaluated using the sit-and-reach test. Each participant performed this test with his shoes removed. The participant's feet were against the sit-and-reach box, and the participant slowly reached forward with hands overlapping and held each stretch for approximately 2 to 3 seconds. The sit-and-reach was measured to the nearest 0.5 cm. Three trials were recorded with the best score used in the analysis. An acceptable ICC (R=0.94) was calculated from the pilot study.

Agility

Participants' agility was measured using the Pro Agility shuttle run. The participant started in the center facing the research assistant. The participant sprinted 5 yards to the right, 10 yards to the left, and then finished by running 5 yards to the right, where he crossed back to the starting line. Any score of the test that resulted from improper positioning (hips and shoulders perpendicular to the starting position) of the body was discarded and the trial was performed again. Three trials with approximately 1 minute of rest between attempts were recorded to the nearest 0.01 second with the best time used in the analysis. Reliability of the pro agility run has been shown to be 0.90 (Stewart, Turner, & Miller, 2014).

Demographics

A questionnaire was used to obtain demographic information including age, sex, race, ethnicity, SES, and sports participation-past and current.

Physical Activity

Physical activity was assessed using the Actigraph GT3x multi-axial accelerometer at the pre-test. Physical activity intensity was determined by using the physical activity cut-points established by Freedson et al (2005). Participants were instructed to wear the accelerometer for one week during all times except sleep and water-based activities. Data were collected in raw mode at a rate of 30 Hertz (Hz) and reintegrated to 1 minute intervals. The accelerometer was worn at the midaxillary line at the level of the iliac crest on the right side of the body. A valid day consisted of wearing the accelerometer for a minimum of 10 hours per day (Troiano, 2008). A minimum of four days (three weekdays and one weekend day) was required to be included in the analysis.

Anthropometrics

Standing and sitting height was measured to the nearest 0.1 cm using a stadiometer (Holtain Limited, Crosswell, United Kingdom) according to standard procedures (Lohman, 1988). Measures were assessed twice and within 0.4 cm, or a third measure was taken. The average of the two closest measures was recorded. Weight was measured using a beam-balance (Seca, Chino, CA). Individuals were measured in light weight clothing with no shoes. Weight was assessed twice and had to be within 0.2 kg.

Maturity Status

Maturity offset, estimated years from peak height velocity (PHV), was used to determine maturity status. It was calculated using the Mirwald and colleagues (2002) equation. Participants were categorized as pre-PHV if the maturational offset was less than one year (-1.1 or more) prior to estimated age at PHV. Participants were categorized as at-PHV if the maturational offset was within one year from estimated age at PHV (-1.0 to +1.0 year). Participants were categorized as post-PHV if the maturational offset was greater than one year from estimated age at PHV (+1.1 or more). The categorical variable of maturity was used as a covariate in the analyses.

Nutrition

Nutrition questions were asked using the School Physical Activity and Nutrition (SPAN) questionnaire (Thiagarajah, et al, 2008). Questions asked about the adolescent's protein, dairy, fruit, vegetable, and whole grains consumption during the previous day. Responses ranged from zero to three or more times. Questions were assessed individually and were used as covariates in analyses.

Training Program

Participants from both training groups attended the program two evenings each week, for the entire eight weeks, on non-consecutive days. The duration of each training session was between 60 and 75 minutes. The warm-up was the same for both groups and was approximately 10 minutes in length. Activities in the warm-up consisted of jogging, dynamic stretching, and bodyweight exercises. At the end of each training session, participants cooled-down with static stretching for approximately 10 minutes. The kettlebell training program consisted of kettlebell exercises, while the dumbbell training program consisted of dumbbell exercises. A kettlebell is a round weight made from steel that resembles a cannonball with a handle attached. Both resistance training groups were designed to elicit as similar responses as possible. In order to compare the two different training modes, the total volume of the training groups was equal. Additionally, the exercises both groups performed were matched in terms of muscles used and the muscle actions. Due to safety concerns of teaching Olympic lifting to adolescents with relatively little training background, the traditional training group engaged in similar exercises that utilize the same muscle groups for a similar muscle action as the KB group. Table 1 shows the description of the exercises and the muscle groups/actions they utilized. The training load and progression was based on previous training intensities involving youth using a periodized model (Fleck & Kraemer, 2004).

Table 1. Description of the resistance training exercises and the muscle groups/actions used.

Kettlebell	Muscle Groups/Actions	Dumbbell
2-hand KB Swing	Ballistic, Triple extension of ankles, knees, & hips, shoulder elevation	Power Shrug (Clean Pull)
1-arm High pull	Ballistic, Triple extension of ankles, knees, & hips, Shoulder, Upper back	1-arm High pull
Shoulder press	Shoulder	Shoulder press
Goblet squat	Hips, Thigh	Front squat

Table 1 (cont'd).

Single-leg deadlift	Hips, Thigh	Single-leg deadlift
Lunges	Hips, Thigh	Lunges

Table 2. Description of the training program volume for adolescents.

	Day 1			Day 2		
	Set 1	Set 2	Set 3	Set 1	Set 2	Set 3
Week 1	X 12	X 12		X 15	X 12	
Week 2	X 15	X 15		X 12	X 12	
Week 3	X 15	X 12		X 15	X 15	
Week 4	X 12	X 12		X 15	X 12	
Week 5	X 15	X 12	X 12	X 15	X 15	X 12
Week 6	X 15	X 15	X 15	X 12	X 12	X 12
Week 7	X 15	X 12	X 12	X 15	X 15	X 12
Week 8	X 15	X 15	X 15	X 12	X 12	X 12

In the table, each "X" denotes the number of repetitions the participant will perform.

Table 2 shows the progression of the resistance training program for both training groups. Prior to the introductory testing, two training sessions allowed each of the participants to become familiar with each of the lifts in the training program and allowed the initial weight to be determined for each of the lifts. During the two introductory training sessions, the starting weight for the 12 repetitions was explored through trial-and-error. For example, on the first set of exercises, if the participant was able to complete 14 or 15 repetitions with a self-selected weight, the weight was increased by approximately five pounds for the second set. This process continued until the 12-repetition maximum was found for each exercise. Throughout the eight-week training program the lifts remained the same. During the first four weeks of the training program, each participant performed two sets of 12-15 repetitions for all of the lifts, using 100% of the 12 RM. For the second four weeks, a third set of 12-15 repetitions was added. Throughout the eight-week training period, when the participant completed 15 successful repetitions of a lift, an increase of 5 pounds to 10 pounds was added to the resistance and the repetitions were dropped down to 12 (Fleck & Kramer, 2004). The training program had structured increases, so both training groups had an equal training volume. For example, on day one of training, the individual performed two sets of 12 repetitions. On day two of training, the individual performed one set of 15 repetitions followed by a set of 12 repetitions. On day three of training, the individual performed two sets of 15 repetitions. On day four of training, the individual increased the weight that was used and decreased the repetitions for both sets back to 12. If the participant could not perform the repetitions based on the structured increases, the training program progressed until the participant could complete all sets with 15 repetitions before increasing the weight used for the exercise. See Table 1 for the full training program. Gradually increasing the number of repetitions and sets during the training program is a key part in designing a training program since it important to properly apply the overload principle, where the body is exposed to a greater stimulus than previously exposed to (Fleck & Kramer, 2004).

Kettlebell Training Program

Kettlebell exercises included kettlebell swings, high pull, shoulder press, goblet squat, single-leg deadlift (SLDL), and walking lunge. During the first four weeks of the training program, each participant performed two sets of 12-15 repetitions for all of the lifts. For the second four weeks, a third set of 12-15 repetitions was added. Throughout the eight-week training period, when the participant completed 15 successful repetitions of a lift, an increase of 5 pounds to 10 pounds was added to the resistance and the repetitions were dropped down to 12 (Fleck & Kraemer, 2004).

Dumbbell Training Program

The dumbbell resistance training group exercises included power shrug, high pull, shoulder press, dumbbell front squat, single-leg deadlift, and walking lunge. During the first four weeks of the training program, each participant performed two sets of 12-15 repetitions for all of the lifts. For the second four weeks, a third set of 12-15 repetitions was added. Throughout the eight-week training period, when the participant completed 15 successful repetitions of a lift, and increase of 5 pounds to 10 pounds was added to the resistance and the repetitions were dropped down to 12 (Fleck & Kraemer, 2004).

After initial testing, the non-exercise control group was instructed not to perform any resistance exercises during the eight weeks of training. At the end of the eight weeks of training, the participants in the control group were allowed to participate in the training program of their choice, if they so desired, for eight weeks.

MEASUREMENT PROTOCOLS

Measures were assessed prior to beginning the training program and immediately following the training program. Demographic variables, exercise and sports history, and nutrition were obtained by questionnaire, which was the first task completed upon arrival to the laboratory. Height, weight, and body composition were next assessed according to procedures mentioned previously. After the warm-up exercises (same as previously described in the preceding training program section), the vertical jump was performed, followed by the horizontal jump. The third test performed was the 40-yard dash, followed by the pro-agility run. After the running tests, the upper- and lower-body strength tests were performed, followed by the upper-body muscular endurance, and lower-body muscular endurance tests. The flexibility test was performed last. The order of the fitness tests was selected to reduce the effect of fatigue on the subsequent measures. The majority of the participants completed the test protocol in this order. There were 15 participants who did not complete the jumping tests first followed by the running tests. This was due to constraints associated with use of the equipment/location. For these participants, the running tests were completed before the jumping tests. After the informed consent process, the participant was instructed on how to wear the accelerometer. The participant returned the accelerometer on the first day of the familiarization period, which was one week after finishing the informed consent.

Evaluation of Training Program

The training programs were evaluated for dose delivered, fidelity, feasibility, and acceptability. Dose delivered was evaluated through documenting the number of training sessions that were offered each week. To assess fidelity, a weight-lifting data sheet was provided to each of the participants at the beginning of the training session to record the number of repetitions and the weight used for each set and was returned at the end of each training session. This data sheet was used to monitor each participant. In order to determine the feasibility of the training program, a questionnaire was created asking about participants' difficulties encountered with participation and any changes that would be suggested to the structure of the training sessions. To assess acceptability, the enjoyment of the training program was measured from the questionnaire.

Power Analysis

A power analysis was conducted using the G Power 3.1 computer program (Faul et al, 2007). Effect sizes from a pilot study were used to help calculate the total sample size. Using an effect size of 0.4 with power of 0.8 and an alpha level of 0.05 for all performance outcomes, a total of 66 participants for all three groups were needed to determine differences between the groups. To determine whether there was a group by time interaction with an effect size of 0.4 with power of 0.8 and an alpha level of 0.05, a total of 21 participants was needed. A sensitivity analysis for 35 participants in the three training groups at an alpha level of 0.05 and power of 0.8 showed capability of detecting an effect size of 0.55.

Statistical Analyses

Descriptive statistics (means, standard deviations, and percentages) were calculated for all outcome variables. Effect sizes (Cohen's d) were calculated for all outcome variables. An alpha level of $p \leq 0.05$ was used to determine statistical significance.

Aim 1: To evaluate differences among 8-week kettlebell resistance training, dumbbell resistance training, and control groups on changes in muscular strength, muscular endurance, muscular power, running agility, running speed, and lower back flexibility in 12- to 17-year-old boys, with and without baseline maturity status as a covariate.

Hypothesis 1: There will be no differences between free-weight resistance training group and kettlebell training group in muscular strength, muscular endurance, power, running agility, running speed, and flexibility from pre- to post-intervention. Both training groups will elicit greater pre- to post-intervention improvements in muscular strength, muscular endurance, muscular power, running agility, running speed, and flexibility when compared to the control group. After controlling for maturity, significant differences will remain between the two training groups and the control group with no significant difference between the dumbbell and kettlebell training group in muscular strength, muscular endurance, muscular power, running agility, running speed, and flexibility from pre- to post-intervention.

Statistical test for Aim 1: An ANCOVA was conducted for percent change for each of the performance measures (vertical jump, horizontal jump, 40-yard dash, pro-agility run, 3 RM bench press, 3 RM leg press, 95 pound bench press, wall sit, flexibility) controlling for baseline measures. Additionally, an ANCOVA was conducted while controlling for the baseline maturity status.

Aim 2: To evaluate differences among 8-week kettlebell resistance training, dumbbell resistance training, and control groups on changes in percent body fat in 12 to 17 year-old boys, with and without protein consumption, fruit consumption, and vegetable consumption, and baseline maturity status as a covariate.

Hypothesis 2: There will be no differences between the free-weight resistance training group and kettlebell training group in percent body fat from pre- to post-intervention. Both training groups will elicit greater pre- to post-intervention improvements in body composition when compared to the control group.

Statistical test for Aim 2: An ANCOVA was conducted to examine the effect of the training program on percent change of percent body fat while controlling for baseline measures. Additionally, an ANCOVA was conducted while separately controlling for nutritional intake, specifically chicken or turkey, pork, seafood, roast beef, or eggs (protein) consumption, fruit consumption, and vegetable consumption, and for baseline maturity status.

Aim 3: To perform a program evaluation of the 8-week training program in terms of dose, fidelity, feasibility, and acceptability.

Hypothesis 3: This aim is not hypothesis driven.

Statistical test for Aim 3: Frequencies and percentages were used for the evaluation of the training program.

CHAPTER FOUR: RESULTS

Forty-nine participants initially enrolled in the study. Eight participants dropped out of the study prior to any data collection. Two participants (two kettlebell) dropped out prior to post-test measures due to scheduling conflicts. Four participants (two kettlebell and two dumbbell) completed post-test measures but did not attend the minimum 70% of the training sessions. Thirty-five participants completed both pre-test and post-test measures and attended the minimum number of sessions. Ten participants were in the kettlebell group, 12 participants were in the dumbbell group, and 13 participants were in the control group. No injuries occurred in any participants during the training sessions. Physical activity data with the accelerometers were lost in the conversion to new computers within the laboratory.

Descriptive statistics (means, standard deviations, and percentages) are presented in Table 3. There were statistically significant differences in vertical jump power output (p = 0.028) and 40-yard dash (p = 0.011) between participants who did not complete the training or attend the minimum number of training sessions versus those who completed the minimum number of training sessions. There were no statistically significant differences among the groups for any of the descriptive variables at pre-test (all $p > 0.05$). There were also no statistically significant differences among groups for any of the pre-test outcome variables (all $p > 0.05$). Training outcomes for the kettlebell, dumbbell, and control groups are presented in Table 4.

Table 3. Whole-group and training group descriptive statistics of 12- to 17-year old males.

Variable	Whole Sample Mean (SD) (n=35)	Kettlebell Group Mean (SD) (n=10)	Dumbbell Group Mean (SD) (n=12)	Control Group Mean (SD) (n=13)
Age (yr)	13.8 (1.35)	14.2 (0.92)	13.5 (1.62)	13.7 (1.36)
Height (cm)	168.1 (11.7)	168.9 (11.1)	168.5 (10.7)	167.2 (13.8)
Weight (kg)	62.4 (14.4)	61.4 (10.2)	62.9 (16.7)	62.7 (16.0)
BMI (kg/m^2)	21.8 (3.5)	21.5 (2.9)	21.9 (3.9)	22.1 (3.7)
BMI Percentile	68.6 (28.2)	64.0 (26.3)	70.0 (28.2)	70.8 (31.4)
Body fatness (%)	22.6 (9.5)	22.0 (11.3)	24.5 (10.0)	21.2 (8.0)
Estimated Age at Peak Height Velocity (years)	13.6 (0.6)	13.8 (0.5)	13.5 (0.4)	13.5 (0.8)
Estimated Years from Age at Peak Height Velocity (years)	0.4 (1.4)	0.8 (1.2)	0.3 (1.6)	0.3 (1.4)

Table 4. Training outcomes of 12- to 17-year-old males.

Variable	Sample pre-test mean (SD) (n=35)	Sample post-test mean (SD)	KB pre-test Mean (SD) (n=10)	KB post-test mean (SD)	DB group pre-test mean (SD) (n=12)	DB post-test mean (SD)	Control group pre-test mean (SD) (n=13)	Control group post-test mean (SD)
Bench Press (kg)	38.3 (9.9)	40.6 (11.4)	38.0 (9.6)	40.4 (10.7)	38.4 (10.9)	41.5 (12.3)	38.6 (10.0)	39.9 (12.0)
Relative Bench Press (%)	62.0 (12.0)	64.0 (13.0)	62.6 (14.4)	65.3 (15.1)	61.7 (10.8)	66.1 (13.4)	63.0 (11.0)	62.0 (12.0)
Leg Press (kg)	118.7 (44.6)	135.2 (42.8)	119.8 (33.0)	143.4 (36.2)	116.5 (51.7)	129.9 (46.5)	119.9 (48.7)	133.6 (46.3)
Relative Leg Press (%)	188.0 (57.0)	214.0 (57.0)	196.4 (47.9)	233.3 (58.3)	185.0 (74.0)	208.0 (61.0)	186.0 (52.0)	206.0 (54.0)

Table 4 (cont'd).

Variable	Sample pre-test mean (SD) (n=35)	Sample post-test mean (SD)	KB pre-test Mean (SD) (n=10)	KB post-test mean (SD)	DB group pre-test mean (SD) (n=12)	DB post-test mean (SD)	Control group pre-test mean (SD) (n=13)	Control group post-test mean (SD)
95 Pound Bench Press (reps)	3.2 (4.6)	4.5 (5.6)	2.9 (4.2)	4.2 (6.0)	3.4 (5.6)	4.4 (6.6)	3.5 (4.2)	4.8 (4.5)
Body fatness (%)	22.6 (9.5)	20.9 (9.7)	22.0 (11.3)	21.8 (12.0)	24.5 (10.0)	21.9 (9.3)	21.2 (8.0)	19.3 (8.6)
Timed Wall Sit (s)	67.2 (45.3)	71.9 (50.2)	61.1 (42.3)	62.1 (40.6)	77.1 (57.8)	105.2 (58.9)	64.9 (37.1)	54.3 (31.1)
Long Jump (m)	1.764 (0.321)	1.812 (0.323)	1.845 (0.352)	1.897 (0.349)	1.729 (0.303)	1.800 (0.286)	1.734 (0.329)	1.756 (0.347)

Table 4 (cont'd).

Variable	Sample pre-test mean (SD) (n=35)	Sample post-test mean (SD)	KB pre-test Mean (SD) (n=10)	KB post-test mean (SD)	DB group pre-test mean (SD) (n=12)	DB post-test mean (SD)	Control group pre-test mean (SD) (n=13)	Control group post-test mean (SD)
Vertical Jump Power Output (W)	4253 (1069)	4309 (1026)	4443 (641)	4445 (750)	4102 (1208)	4230 (1071)	4247 (1240)	4277 (1220)
40-Yard Sprint	6.10 (0.74)	6.09 (0.79)	6.06 (0.86)	6.03 (0.72)	6.09 (0.63)	6.07 (0.78)	6.13 (0.80)	6.14 (0.91)
Agility (s)	5.47 (0.61)	5.42 (0.56)	5.33 (0.61)	5.32 (0.42)	5.46 (0.66)	5.50 (0.60)	5.6 (0.6)	5.4 (0.6)
Flexibility (cm)	23.0 (8.4)	24.3 (8.9)	23.4 (5.1)	25.5 (8.0)	22.3 (10.0)	23.3 (9.5)	23.3 (9.7)	24.3 (9.6)

*KB = Kettlebell; DB = Dumbbell

Table 5. Percent change for training outcomes of 12- to 17-year-old adolescent boys.

Variable	Sample Percent Change Mean (SD)	Kettlebell Group Percent Change Mean (SD)	Dumbbell Group Percent Change Mean (SD)	Control Group Percent Change Mean (SD)
Bench Press	5.2 (6.8)	6.5 (5.6)	7.7 (5.1)	1.9 (8.1)
Relative Bench Press	3.4 (7.6)	4.6 (5.6)	6.8 (5.8)	-0.7(8.9)
Leg Press	20.3 (30.1)	24.8 (38.3)	21.2 (33.7)	16.0 (19.7)
Relative Leg Press	18.0 (28.8)	22.4 (36.4)	19.9 (32.4)	12.8 (18.4)
95 Pound Bench Press	32.0 (63.6) (n=32)	17.5 (37.5) (n=9)	46.7 (93.6) (n=12)	27.8 (36.3) (n=11)
Body Fatness	-8.3 (13.6)	-2.1 (9.5)	-11.5 (13.7)	-10.3 (15.5)
Timed Wall Sit	32.0 (84.4)	45.2 (128.3)	58.8 (62.5)	-3.0 (45.7)
Long Jump	2.9 (6.3)	3.1 (6.5)	4.5 (5.4)	1.3 (7.1)
Vertical Jump Power Output	1.9 (8.5)	-0.2 (6.3)	4.8 (11.8)	0.7 (5.7)
40-Yard Sprint	-0.2 (5.8)	-0.2 (6.0)	-0.4 (6.5)	0.0 (5.3)
Agility	-0.6 (7.3)	0.2 (5.5)	1.1 (9.2)	-2.8 (6.4)
Flexibility	7.4 (19.7)	8.4 (24.7)	7.5 (17.4)	6.5 (19.0)

Muscular Strength

A significant effect of training group was found for relative upper body strength, $F(2, 31) = 3.624$, $p = 0.039$. The dumbbell training group was significantly better than the control group (mean difference = 7.49, $p = 0.037$). After controlling for the pre-test measure and maturity, a significant effect of training group remained, $F(2, 30) = 4.533$, $p = 0.018$. The effect size of the dumbbell training program was $d = 0.362$. No significant effect of training was found for relative lower body strength ($p = 0.534$).

Muscular Endurance

There was no significant effect of training for upper body muscular endurance ($p = 0.561$). There was no significant effect of training for lower body muscular endurance when controlling for the pre-test measure alone ($p = 0.062$). However, when controlling for the pre-test measure and maturity, a significant effect of training was found, $F(2, 30) = 3.549$, $p = 0.041$. The dumbbell training group was significantly better than the control group (mean difference = 73.7, $p = 0.039$). The effect size of the dumbbell training program was $d = 0.471$. There were no statistically significant effects of training for all remaining training outcomes (all $p > 0.05$).

Figure 1. Effects of 8 weeks of resistance training on relative upper body muscular strength.

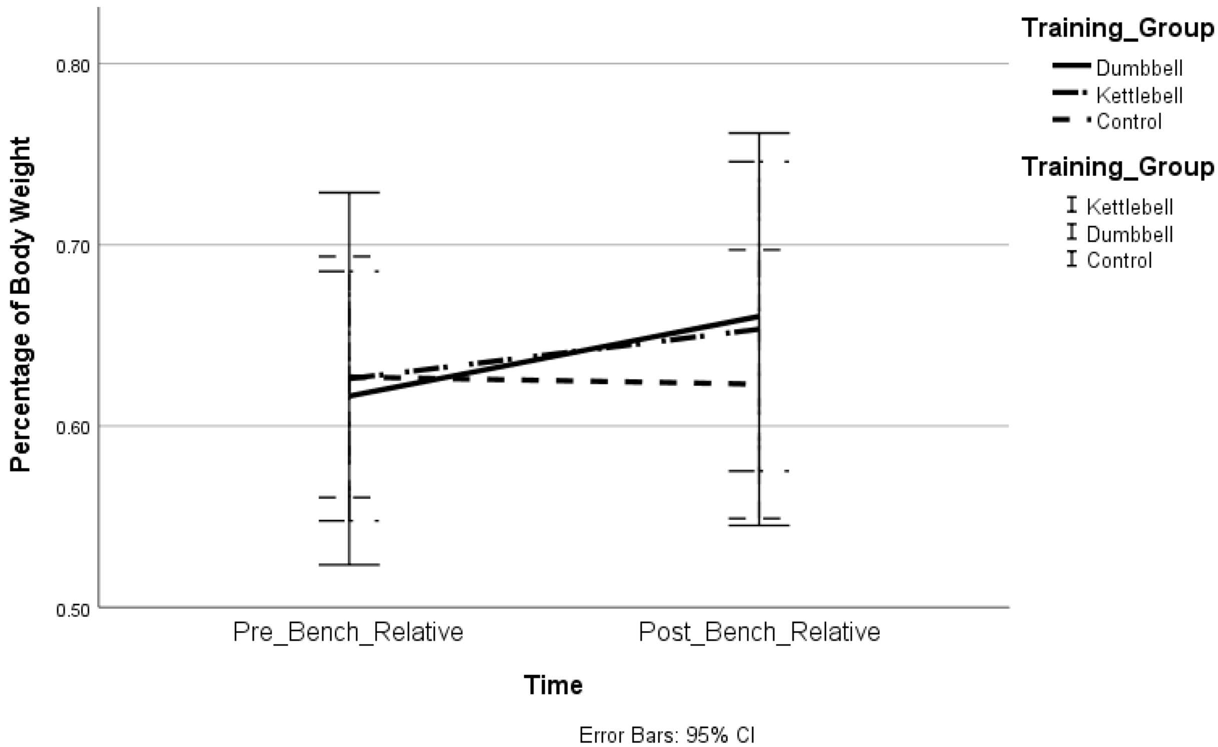
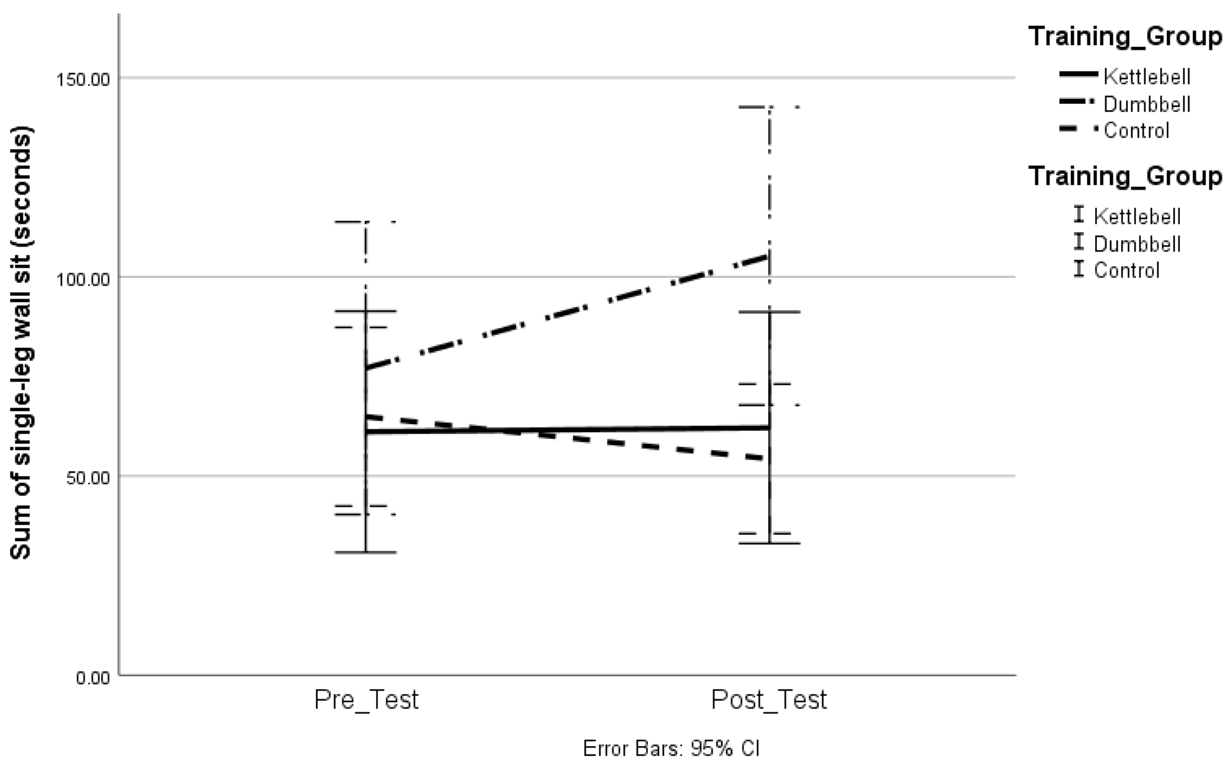


Figure 2. Effects of 8 weeks of resistance training on lower body muscular endurance.



Participants in the two training groups attended 96.0% of the 16 training sessions (dose). All participants but one reported enjoying participating in the resistance training program (acceptability). All participants in the training groups thought the timing of the training sessions was convenient for them and that the length of each session was good for them (feasibility). When asked about things that could improve the training program, one participant (kettlebell) commented about the warm-up, one participant (dumbbell) commented to add more cool-down stretches, and one participant (kettlebell) commented to make it more game like (feasibility). Two participants (one dumbbell and one kettlebell) commented on the location of the training sessions (feasibility). The majority of participants answered there were no other competing factors that prohibited them from participating in the training sessions (feasibility). Of the sessions delivered, 70.7% of them were delivered as intended (fidelity). All but three participants in the control group did not find it difficult to refrain from lifting weights. Two participants commented on conditioning for their extracurricular sports. One participant commented on the activities that he did required him to engage in lifting (fidelity).

CHAPTER FIVE: DISCUSSION

An 8-week resistance training program elicited some improved fitness outcomes in 12- to 17-year-old adolescent boys. The hypotheses for upper body muscular strength were partially confirmed with only the dumbbell training group improving and no change for the kettlebell group. The hypotheses for percent body fat, running speed, running agility, long jump, vertical jump, lower body muscular strength, upper body muscular endurance, lower body muscular endurance and flexibility were not confirmed, with no significant differences among the three training groups. However, a difference for lower body muscular endurance emerged when controlling for the pre-test measure and maturity. Participants attended the majority of the training sessions and mostly enjoyed the program.

The overall goal for any training program should be to improve the physiologic characteristics of the participants and to reduce the likelihood of musculoskeletal injury (Sheppard & Triplett, 2016). The present study utilized a training volume that was typical for improving muscular strength and endurance in adolescent boys (Sheppard & Triplett, 2016; Fleck & Kraemer, 2004). There were some aspects of the training exercises during which the participants were asked to complete the movement as forcefully as possible, specifically the kettlebell swing in the kettlebell group and the power shrug in the dumbbell group. Both exercises utilized the triple extension of the ankles, knees, and hips, which is typical of power training. The training programs were designed with the same movement patterns and training volume, so if any difference was detected, it could be attributed to the mode of exercise.

No known studies exist in the literature comparing modes of resistance training in adolescents, especially using kettlebells. In adults, one study elicited a greater improvement from pre-test to post-test in the back squat from a weightlifting training program than from a kettlebell training program (Otto et al, 2012). In comparing Olympic weightlifting and traditional weightlifting to a control group for vertical jump improvement in adults, large effect sizes were found favoring both weight training groups (Channel et al, 2008). It appears as though different weight training modes exhibit different training effects, with no comparison studies available in the adolescent literature.

Muscular Strength

In the current study, after eight weeks of resistance training twice per week, relative (to body weight) upper body muscular strength increased from pre-test to post-test for the dumbbell group only. These results are consistent with other resistance training studies in which positive changes in muscular strength were found (Faigenbaum et al, 1993, 1996, 2005). Performing multiple sets with 12 to 15 repetitions per set appears to provide enough training stimulus to promote improvements in upper body muscular strength (Faigenbaum et al, 1993). The current study showed effect sizes much lower than others in the scientific literature. One possible explanation for this is that many of the studies utilized the same equipment for both testing and training. When using the same mode of training and testing, there is a greater effect of specificity of training (Behm, 1995). In the adult kettlebell literature, Manocchia and colleagues (2013) showed that performing 10 weeks of resistance training with kettlebells improved muscular strength assessed via a bench press. While muscle activation was not measured in the current study, it may be possible there is a difference in the muscle activation using different resistance training modes. All known studies that have utilized EMG to investigate muscle activation using kettlebells have focused on the hips, legs, and lower back (Zebis et al, 2013; Van Gelder et al, 2015; Andersen et al, 2016). It may be possible that there is a difference in the development of muscular strength since the mass of the kettlebell lies outside of the hands, whereas the mass of the dumbbell lies within the hands. This may result in a reduced training load for the participants affecting the overall muscular strength development. This would be an area of further investigation. Therefore, it may be that using alternative modes of training might require longer durations in order to improve upper body strength.

Maturation did not appear to have an effect on the development of muscular strength in the current study. After controlling for maturation, only the participants in the dumbbell group improved their upper body strength after 8 weeks of resistance training. Approximately half of the sample were at their estimated age at peak height velocity. At the time of peak height velocity, boys usually show significant improvements in upper and lower body strength. On average, the peak muscular strength development occurs approximately 1.2 years after peak height velocity (Malina, Bouchard, Bar-Or, 2004). In a test of pushing strength of the shoulders, the maturation process, body mass, and specifically muscle mass, have been shown to play a role in the development of muscular strength (Katzmarzyk et al, 1997). While the current study investigated dynamic strength using a bench press, in tests of static strength, body mass was an important predictor of muscular strength development (Beunen et al, 1981). However, few investigators who have evaluated resistance training outcomes across adolescence have controlled for maturation. The current study utilized a categorical variable for maturity. Similarly, in a 28-week study of resistance training in adolescents comparing two different training programs, the participants were similar in maturity offset (estimated years from peak height velocity), and the two groups had similar improvements in strength, power, and speed (Pichardo et al, 2019). However, the study did not include a non-weight training control group, so the comparability of the results to the normal growth pattern remains unclear (Pichardo et al, 2019). Faigenbaum and colleagues (1993) assessed maturity via secondary sex characteristics, but the authors did not control for maturation in the statistical analysis, so it is unclear what effect maturational status had on the study outcomes. While the current results did not show an effect of maturation on muscular strength, it may be important to consider the effect of growth and maturation on the training outcomes across a large age range of adolescents.

Results from the current study did not show improvements in relative lower body muscular strength as a result of resistance training, which is in contrast to the current literature. Resistance training twice per week has been shown to improve lower body muscular strength (Faigenbaum et al, 1993, 1996; Chelly et al, 2009; Muehlbauer et al, 2012). Specificity of training may have an influence in an eight-week resistance training program with adolescents. Adolescents in the current study were tested on the leg press machine and trained by performing squats using either kettlebells or dumbbells. Faigenbaum et al. (1993, 1996) tested and trained adolescent boys and girls on the leg extension machine with large improvements in lower body muscular strength. Faigenbaum and colleagues (1996) utilized multiple (2-3) sets of six repetitions to improve participants' lower body muscular strength by 53%. Chelly and colleagues (2009) had adolescent soccer players use and test on a 1-RM back squat, which improved after eight weeks of training. The training program utilized in that study started at 70% of the individual's 1RM and increased to 90% of the individual's 1RM (Chelly et al, 2009). Thus, in a short training program with non-traditional equipment, the specificity of training likely impacts the training outcome.

Due to a wide age range in our sample, the total amount of weight lifted was divided by the participant's body weight during analysis to allow for a better comparison. However, this scaling of the amount of weight lifted to body weight does have some limitations, in that it overestimates muscular strength in smaller individuals and underestimates muscular strength in larger individuals (Malina, Bouchard, Bar-Or, 2004). The majority of training studies in youth have typically investigated the total amount of weight (absolute weight) lifted for the various exercises. When there is a wide range of ages (and thus maturity levels), using the total weight lifted introduces some complications in interpreting the effect of a resistance training program. Although not measured, it is probable that adaptations in the neuromuscular system, specifically motor unit recruitment and the rate of motor unit firing can explain some of the large increases that were obtained in the current study (MacIntosh, Gardiner, McComas, 2006). Additionally, during the testing and training sessions, a low instructor-to-participant ratio was utilized, which was no more than 1-to-2, which allowed the instructor to provide corrective feedback on the exercise as well as motivation during each exercise. Therefore, it is important to consider how the outcome variable is presented in order to properly interpret it.

Muscular Endurance

Upper body muscular endurance did not improve across the eight weeks. In the current study, the assessment for upper body muscular endurance was not appropriate for the participants on the younger age range of the sample, as it was too much weight to complete the assessment. Approximately half of the participants were not able to perform a single repetition with the weight during their attempts.

Lower body muscular endurance in the current study did improve as a result of resistance training, which is similar to the literature. Lower body muscular endurance in adolescents has been shown to improve with resistance training over eight weeks (Faigenbaum et al, 1999; Faigenbaum et al, 2005). No studies in the kettlebell literature have investigated the effects of training on muscular endurance. The overall training load may have an effect on the improvements in muscular endurance. Using a high repetition maximum training program (15-

20 repetitions), children improved in a 15-repetition maximum leg press after eight weeks of training (Faigenbaum et al, 2005). Additionally, comparing the training load between a low repetition with a heavy load group and a high repetition with a moderate load group resulted in the high repetition (13-15 repetitions) group performing significantly more repetitions on a leg extension exercise (Faigenbaum et al, 1999). Specificity of training may have influenced the outcomes of the lower body muscular endurance, as the participants were testing using a single-leg wall sit and trained using either kettlebells or dumbbells for three lower body exercises (Behm, 1995). Therefore, using different resistance training modes could have some effect on lower body muscular endurance improvement.

40-Yard Dash

Eight weeks of resistance training did not improve sprint performance in the current sample, which is in contrast to the current literature. In adults, Swinton et al determined that lower body muscular strength normalized to body weight was the single best predictor of a 30-m sprint (Swinton et al, 2014). By improving muscular strength, the individual can generate more force in each stride, which allows for a faster stride rate (DeWeese & Nimphius, 2016). Previous literature has shown that resistance training is beneficial for improving sprint performance in adolescents (Chelly et al, 2009; Sander et al, 2013). After eight weeks of training twice per week using intensities progressively increasing from 70% to 90% of the individual's 1RM, the running velocity of older adolescents improved compared to the control group (Chelly et al, 2009). However, training three times per week for seven weeks in young adult males using a combination of heavy strength training, power training, and ballistic training methods did not improve sprint speed over 15-meters or 30-meters (Saez de Villarreal et al, 2013). In a 16-week resistance training program, a combined strength and sport specific training program, which focused on the development of running speed and agility, elicited improvements in a 30-meter sprint. However, at the 8-week test, there were no improvements in sprint performance among the combined strength and sport performance, sport performance only, or control groups (Christou et al, 2006). Thus, it appears that higher training intensities must be utilized in the training program in order to improve sprint performance in eight weeks. If lower intensities are utilized, it may take up to 16 weeks to see improvement.

Agility

The ability to change direction did not improve after eight weeks of resistance training, which is similar to results found in the previous literature (Faigenbaum et al, 2007; Christou et al, 2006; Falk & Mor, 1996). The agility of both the combined resistance and sport performance and the sport performance only groups improved after eight weeks. The sport performance training focused on small group games with limited players as well as training for developing running speed and agility. Since resistance training did not affect agility performance, the addition of the sport performance training indicates the specificity of the sport, since there is a high degree of change in direction in the sport of soccer (Christou et al, 2006). The ability to change direction relies heavily on the development and application of high, quick force production from the legs (Spiteri et al, 2015). Since the current training program did not elicit improvements in vertical jump or long jump, it was not surprising to see there were no improvements in the ability to change direction.

Standing Long Jump

Standing long jump did not improve after eight weeks of resistance training in adolescents in the present investigation, which is in contrast to the literature. Pichardo et al (2019) designed a 28-week resistance training study using a structured training program gradually progressing to 2-5 sets with 2-4 repetitions and improved horizontal jumping distance. The authors concluded that the combined resistance training and weightlifting group, which had a higher proportion of high velocity movements, showed similar improvements to the resistance training group alone, which had a greater allowance for external loading (Pichardo et al, 2019). When performing the exercises in the current study, participants were told to complete the movements as quickly as possible and they were able to increase weight as they progressed through the training program. Thus, it appears as though using high repetitions with low to moderate weight quickly is not appropriate for improving standing long jump in adolescents.

Vertical Jump

Vertical jump did not improve after eight weeks of resistance training, which is similar to what has been shown previously in the literature (Moraes et al, 2013). Using three sets of 12 to 15 repetitions and training three times per week did not improve standing long jump and vertical jump in boys aged 14 to 18 years (Moraes et al, 2013). The current study did not include plyometric training exercises, which have been shown to improve tasks that depend on muscular power (Sohnlein et al, 2014; Chelly et al, 2010, 2014). However, participants in the current study were instructed to complete the high pull as quickly as possible, mimicking a power assistance exercise (USA Weightlifting, 2003).

The training loads (12-15 repetitions) used in the current study are not typically used when training for muscular power, so it is possible that the stimulus was not sufficient to improve the standing long jump or vertical jump. The training loads that have typically been used in training studies where muscular power has improved have been greater than 70% to 75% of the individual's 1 RM (Rhea et al, 2008). Using Olympic lifts or power training exercises, both training protocols improved the vertical jump after 12 weeks of training in adolescent boys (Channell et al, 2008) and pre-adolescent boys (Chaouachi et al, 2014).

In other studies where resistance training helped improve these outcomes, various plyometric training exercises were used (Sohnlein et al, 2014; Rhea et al, 2008). In a six-week training program in college-aged individuals, a combination of strength and plyometric exercises elicited the greatest improvement in strength, although both strength training and plyometric training alone improved strength outcomes. The strength training portion was performed with intensities ranging from 70% to 100% of the one-repetition maximum (Adams et al, 1992). These power-type outcomes rely on the stretch-shortening cycle (SSC) to perform the movement. Additionally, rate of force development (RFD) is an important component of tasks concerning muscular power. In order to maximize the RFD, the individual must perform the movement as fast as possible, thus moving "explosively" (Fleck & Kraemer, 2014). Thus, when trying to improve jumping ability incorporating exercises that force the participant to move quickly may elicit the greatest improvement.

Plyometrics may not be required to improve the jumping ability of adolescents. In a study using adolescent soccer players, exercises not specific to jumping were chosen as a part of the training protocol. Improving the muscular strength of the participants, which helped the participants exert additional force, improved their vertical jumping ability by approximately 4 centimeters after eight weeks of training (Christou et al, 2006). Relative muscular strength was highly correlated with 20-meter sprint performance in adolescents (Comfort et al, 2014). Using a functional training program in pre-pubertal children, countermovement jumping ability increased from pre-test to post-test (Yildiz et al, 2019). Thus, improving muscular strength alone may be able to improve jumping ability of adolescents, but the training stimulus was not enough in the current study.

Percent Body Fat

Percent body fat was not reduced across the eight weeks of training, which is in contrast to the literature. Previous literature has shown that decreases in percent body fat are possible after training twice per week for eight weeks in children (Faigenbaum et al, 1993). Performing three sets of five exercises twice per week reduced the sum of seven skinfolds (Faigenbaum et al, 1993). Lillegard and colleagues (1997) found a decreased sum of skinfolds after training three times per week for 12 weeks. It appears as though a greater training volume is needed to improve percent body fat in eight weeks of resistance training.

Flexibility

Flexibility did not improve after eight weeks of training. Flexibility exercises were incorporated into the cool-down after each training session, but may not have been sufficient to elicit improvements in the flexibility assessment. One previous study that compared a traditional training program with resistance bands, a functional training program with minimal equipment, and a control group elicited improvements in flexibility, as assessed with the sit-and-reach test. The two training groups trained three times per week with 10-minute cool-down sessions consisting of stretching exercises (Yildiz et al, 2019). When incorporating stretching across all types of activity, it is possible to improve the flexibility of the participant, but that did not occur in the current study.

Program Evaluation

When evaluating the program, it appeared as through the majority of participants enjoyed the program and were able to see improvement in their overall fitness. The days and times the sessions were offered appeared to be appropriate for the participants. Two participants, both in the dumbbell group, commented on the competing factors, stating that their in-season sport schedule made the training difficult to schedule. The majority of participants in the control group were able to refrain from participating in a structured weight training program. Three participants in the control group stated they were not able to refrain from lifting weights. Two of those participants stated that conditioning for their sport made it difficult. One participant stated that the activities he engaged in made him lift things. Since all three groups were able to participate in their respective sports, it is unlikely this would have had a major effect on the results.

A strength of the study was the fact this is one of the first studies to compare different training modes, specifically using kettlebells, in adolescent boys. Training volumes were equal between the two training groups, which allowed a fair comparison of the effectiveness of the different training modalities. Additionally, exercises selected for the different training programs utilized similar muscle actions, which also allowed a fair comparison of the effectiveness of the training programs. Assessment of maturational level using estimated age at peak height velocity (PHV) has not been performed in many resistance training studies. It was important to estimate age at PHV with the study having participants who were near their adolescent growth spurt, since maturation can have an effect on the development of many health- and skill-related tasks (Malina, Bouchard, Bar-Or, 2004).

A limitation of the study is the overall sample size. Recruiting for this study was particularly difficult, as many adolescents who were contacted were initially interested in participating but had many other extracurricular activities that prohibited them from committing to training twice per week for eight weeks. A possible solution for this issue would be to conduct the study within the physical education classes at various schools to eliminate the participation in the study as an additional extracurricular activity, when the adolescent is already busy with other activities. Physical activity data with the accelerometers were lost in the conversion to new computers within the laboratory, so it is unclear of the effects that physical activity would have on the development of the outcome variables. For the leg press, 40-yard dash, agility, and flexibility tests, the observed power was quite low to detect differences among the training groups, so any differences due to training effects may be obtained with more participants.

Although the training modes were not equivalent across all training outcomes, practitioners should not be afraid of incorporating a variety of training modalities into their resistance exercise programming. By introducing a new stimulus to the participant, the neural system must adapt and incorporate new recruitment patterns in order to perform the desired movement (Behm, 1995). Additionally, including new training modes into programming is a way to keep the participant engaged and not become bored. The use of a variety of training modes ultimately has a place in the overall exercise prescription for participants.

In conclusion, an eight-week resistance training program that incorporated training twice per week improved upper body muscular strength in adolescent boys. Improvements were found only in one mode of resistance training indicating that the mode of training may be important in a short-term training program as well as the overall training load/volume. This study indicated that non-traditional modes of resistance training did not elicit improvements in overall physical performance. Further study of the non-traditional modes of training (kettlebell) are warranted to determine their effects on training performance, such as a long-term training program. The specificity of training and testing are also important to consider in the development of a comprehensive resistance training program.

APPENDIX

Appendix A: Description of the training exercises. Each set is with 100% of 12 RM. If the participant cannot perform the total number of repetitions for each set, he will progress until 15 repetitions can be performed for each set, then the number of repetitions will decrease to 12 with the weight increasing.

Kettlebell Exercises

KB Swing: The KB will start between the participant's feet, which will be approximately hip-width apart. With a 2-handed overhand grip, the participant will squat down to pick up the KB, keeping a neutral spine. From this position, the participant will stand up quickly, extending the ankles, knees, and hips, while simultaneously raising the KB to shoulder height. The participant will then lower the weight back to the starting position and perform the repetition again.

1-Arm High Pull: With a single-hand grip, the KB will start at approximately thigh level. The participant's feet will be approximately shoulder-width apart. The participant will pull the KB vertically, using the hips, shoulder, and upper back, until the KB is just below shoulder height. The participant will lower the KB back to the starting position and perform the repetition again. After the appropriate number of repetitions, the participant will perform the exercise with the opposite hand.

1-Arm Shoulder Press: With the participant's feet approximately shoulder-width apart, the KB will start at shoulder height. The participant will raise the KB above the head. The participant will lower the KB back to shoulder height and perform the repetition again. After the appropriate number of repetitions, the participant will perform the exercise with the opposite hand.

Goblet Squat: Holding the KB close to the chest with feet placed approximately shoulder-width apart, the participant will sit back and lower the hips until the thighs are approximately parallel with the floor. The participant will rise up to a standing position and perform the repetition again.

Single-leg Deadlift: Balancing on one foot, the KB will be in the opposite hand (i.e., balance on right foot, KB in left hand). The KB will be at approximately thigh height and the participant will lean forward while simultaneously raising the leg behind. The participant will lean forward until there is a stretch in the back of the leg that he is balancing on, while keeping a neutral spine. The participant will rise back up to a standing position and perform the repetition again. After the appropriate number of repetitions, the participant will perform the exercise with the opposite side.

Walking Lunges: Using one KB, the participant will take a step forward and lower the back leg to a position just above the floor. The participant will then alternate lunges in a walking manner until the appropriate number of repetitions have been completed for each lower limb.

Dumbbell Exercises

Power Shrug (Clean Pull): Feet will be placed approximately hip-width apart and the upper body will have a slight bend at the waist. Dumbbells will start at approximately knee height and the participant will pull the dumbbells vertical rapidly, extending the ankles, knees, and hips, while simultaneously elevating the shoulders. The participant will lower the dumbbells back to the starting position and perform the repetition again.

1-Arm High Pull: With a single-hand grip, the dumbbell will start at approximately thigh level. The participant’s feet will be approximately shoulder-width apart. The participant will pull the dumbbell vertically, until the dumbbell is just below shoulder height. The participant will lower the dumbbell back to the starting position and perform the repetition again. After the appropriate number of repetitions, the participant will perform the exercise with the opposite hand.

1-Arm Shoulder Press: With the participant's feet approximately shoulder-width apart, the dumbbell will start at shoulder height. The participant will raise the KB above the head. The participant will lower the dumbbell back to shoulder height and perform the repetition again. After the appropriate number of repetitions, the participant will perform the exercise with the opposite hand.

Front Squat: Holding the dumbbell close to the chest with the feet approximately shoulder-width apart, the participant will sit back and lower the hips until the thighs are approximately parallel with the floor. The participant will rise up to a standing position and perform the repetition again.

Single-leg Deadlift: Balancing on one foot, the dumbbell will be in the opposite hand (i.e., balance on right foot, dumbbell in left hand). The dumbbell will be at approximately thigh height and the participant will lean forward while simultaneously raising the leg behind. The participant will lean forward until there is a stretch in the back of the leg that he is balancing on, while keeping a neutral spine. The participant will rise back up to a standing position and perform the repetition again. After the appropriate number of repetitions, the participant will perform the exercise with the opposite side.

Walking Lunges: Using one dumbbell, the participant will take a step forward and lower the back leg to a position just above the floor. The participant will then alternate lunges in a walking manner until the appropriate number of repetitions have been completed for each lower limb.

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