2019

A Comparison Between the Efficacy of Traditional Periodization, Undulating Periodization, and Plyometric Training and Their Lasting Effects on Performance Outcomes in Youth Athletes. A Systematic Review and Meta-Analysis

Andre McIntyre
South Dakota State University

A COMPARSION BETWEEN THE EFFICACY OF TRADITIONAL PERIODIZATION, UNDULATING PERIODIZATION, AND PLYOMETRIC TRAINING AND THEIR LASTING EFFECTS ON PERFORMANCE OUTCOMES IN YOUTH ATHLETES. A SYSTEMATIC REVIEW AND META-ANALYSIS.

BY

ANDRE MCINTYRE

A thesis submitted in fulfillment of the requirements for the

Master of Science

Major in Nutrition and Exercise Science

Specialization in Exercise Science

South Dakota State University

2019

A COMPARISON BETWEEN THE EFFICACY OF TRADITIONAL PERIODIZATION, UNDULATING PERIODIZATION, AND PLYOMETRIC TRAINING AND THEIR LASTING EFFECTS ON PERFORMANCE OUTCOMES IN YOUTH ATHLETES. A SYSTEMATIC REVIEW AND META-ANALYSIS

ANDRE MCINTYRE

This thesis is approved as a creditable and independent investigation by a candidate for the Master's of Science in Exercise Science and Nutrition degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Matthew Vukovich, Ph.D.
Thesis Advisor Date

Kendra Kattelmann, Ph.D, RDN, LN, FAND. Date
Head, Department of Exercise Science and Nutrition

Dean, Graduate School Date

I dedicate this systematic review and meta-analysis to my family, friends, academic advisor, mentors and co-workers.

ACKNOWLEDGEMENTS

I want to first I want to thank my Lord and Savior Jesus Christ.

I want to thank my advisor Dr. Matt Vukovich. Your guidance has helped guide me as I took a journey back to college. I cannot express how thankful I am to have you a mentor that pushed me to be the best version of myself, but also reminded me that I am human. I am honored to have been given the opportunity to be one of your graduate student. It has been a pleasure.

I want to acknowledge Sam Modrick and Sean O'Connor. No one word or phrase can explain how grateful I am to have both of you a part of my life. From making up a song to remember the Kreb's cycle our first summer together to our lengthy professional discussions, these memories I will cherish forever. Both of you made me want to be better every day. The work ethic, knowledge and passion you have is contagious. Along this journey I did not know I would meet two of my best friends. Thank you.

To my family and especially my mother, you have hidden in the shadows on this journey but have been the foundation, which I stand on. The love and support I receive reminders me of why I am who I am. Grandpa, I wish you were here to enjoy this moment with us but I know smiling a little bit bigger today. I love you all.

"I can do all things through Christ which strengthens me." – Philippians 4:13

TABLE OF CONTENTS

ABBBREVIATIONS

1 Repetition Maximum – 1 RM

Back Squat – BS

Central Nervous System – CNS

Change of Direction - COD

Confidence Intervals – CI

Countermovement Jump – CMJ

Degree of Freedom – DF

Depth Jump – DJ

Effect Size – ES

General Adaptation Syndrome – GAS

Long Term Athlete Development –LTAD

National Federation of State High Schools Associations – NFHS

National Strength and Conditioning Association – NSCA

Preferred Reporting Items for Systematic Review and Meta-Analyses – PRISM

Rate of Force Development – RFD

Specific Adaptation to Imposed Demands – SAID

Standardized Mean Differences – SMD

Standing Long Jump – SLJ

Stretch Shortening Cycle –SSC

Vertical Jump – VJ

LIST OF TABLES & FIGURES

ABSTRACT

A COMPARSION BETWEEN THE EFFICACY OF TRADITIONAL PERIODIZATION, UNDULATING PERIODIZATION, AND PLYOMETRIC TRAINING AND THEIR LASTING EFFECTS ON PERFORMANCE OUTCOMES IN YOUTH ATHLETES. A SYSTEMATIC REVIEW AND META-ANALYSIS.

ANDRE MCINTYRE

2019

Recreational and competitive youth (≤ 16 years old) sport participation over the years has increased in recent years. As a result of increased sport participation an emphasis on sport performance training and more particularly resistance training along with plyometric training have been on the rise. Resistance training and plyometric training can improve sports performance, rehabilitate injuries, prevent injuries, and enhance long-term health in adolescent athletes. Resistance training can be periodized numerous different ways, but the most popular training methods are traditional periodization, undulating periodization, and plyometric training. This systematic review and meta-analysis examined studies that compared traditional periodization, undulating periodization, plyometric training to each other and/or a control group. Studies examined the effects of specific resistance training protocols on sports performance outcomes such as strength, speed and power. The systematic search of PubMed revealed 23 articles that were appropriate for the inclusion criteria. The current meta-analysis aimed to evaluate the following: 1) training protocols showed greater improvements in performance outcomes when compared to a control group except for undulating periodization on power performance outcomes and plyometric training for strength on strength outcomes, 2) traditional periodization showed greater improvements on strength and power performance outcomes when compared to undulating periodization, 3) traditional periodization showed significant improvements in strength performance outcomes when compared to plyometric training but not speed and power performance outcomes. The studies included training programs that were short in nature and consisted of individuals <16 years old and >16 years old that were either trained or novice. Unfortunately, there were no articles that compared undulating periodization to a control group for power performance outcomes, traditional vs undulating periodization for speed performance outcomes or no studies that compared undulating periodization vs plyometric training on all performance outcomes. Limitations of the current study are the sample size of articles reviewed, articles featured individuals >16 years old, and novice and experienced individuals. Improvements in sport performance outcomes can be enhanced by participation in resistance training. From the review traditional periodization provides greater improvement than undulating periodization on performance outcomes. The evidence is inconclusive when comparing traditional periodization to plyometric training on performance outcomes other than strength.

Key Words: linear resistance training, undulating periodization, plyometrics, children, adolescents

CHAPTER 1

REVIEW OF LITERATURE

Table 1. Characteristics of included studies

Study (Author & Outcome Measure)	Article name	Group Comparison (n)	Outcome measure	Gender/ Age (mean)	Training Status/RT Experience	Training Period Specifics	Outcome/ Conclusion
Harries et al., 2017 Changes in Sprint & Jumping Performance in Competitive Adolescent Rugby Union Players	*Effects of 12-week resistance training on sprint and jump performance in competitive adolescent rugby union players*	Traditional Undulating Control (26)	St: 1RM Squat Sp: 10m Run, 20m Run P: Jump Height non weighted, Jump Height weighted	M - 16.15	Competitive rugby union players (trained)	12 weeks: 2x/wk (60 mins)	St: Und>Trad Sp: Und=Trad P: Und=Trad
Bartolomei et al., 2015 Compare the Effects of Block v Weekly Undulating Programs on Strength in Recreationally Trained Women	*Block v Weekly Undulating Periodized RT Programs in Women*	Traditional Undulating (17)	St: 1 RM Squat, 1 RM Deadlift, 1 RM Bench Press, Midthigh pull P: CMJ, Peak RFD	F - 24	Recreational - University Weight Training Class (trained)	10 weeks: 2x/wk	St: Und>Trad P: Und=Trad
Santos et al., 2012 Determine the Effects of a Resistance Training Program on Explosive Strength in Adolescent Male Basketball Players	*The Effects of Resistance Training on Explosive Strength Indicators in Adolescent Basketball Players*	Undulating Control (25)	P: CMJ, Peak RFD	M - 14.35	Recreational - Adolescent Basketball Players (untrained)	10 weeks: 3x/wk	P: Und>Con
Miranda et al., 2011 Compare the Effect of Resistance Training Programs on Strength Gains in Upper and Lower Body Exercises in Recreationally Trained Men	*Effects of Linear v Daily Undulatory Periodization RT on Maximal and Submaximal Strength Gains*	Traditional Undulating (20)	St: Leg Press 1-RM, Leg Press 8-RM, BP 1-RM, BP 8-RM	M - 26.25	Recreational Active (trained)	10 weeks: 3x/wk	St: Und>Trad
Apel et al., 2011 Compare TD Periodized Strength Training with WUD Periodized Strength Training in Men with Previous Strength Training Experience	*A Comparison of Traditional and Weekly Undulating Periodized Strength Training Programs with Total Volume and Intensity Equated*	Traditional Undulating Control (42)	St: Back Squat, Flat Bench press, Leg Extension, Lat Pulldown, Db Shoulder Press	M - 22	Recreational Active (trained)	12 weeks: 4x/wk	St: Trad>Und
Prestes et al., 2009 Compare the Strength Gains Between Linear Periodization and Daily Undulating Periodization Weight Training Program over 12 weeks of Training	*Comparison Between Linear and Daily Undulating Periodized Resistance Training to Increase Strength*	Traditional Undulating (40)	St: Bench Press, 45° leg press, Arm (biceps) Curls	M - 21.75	Recreational Active (trained)	12 weeks: 4x/wk (50 mins)	St: Und>Trad

Study (Author & Outcome Measure)	Article name	Group Comparison (n)	Outcome measure	Gender/ Age (mean)	Training Status/RT Experience	Training Period Specifics	Outcome/ Conclusion
Rhea et al., 2002 Examine A More Intensive Approach to Undulating Periodization by Altering Volume and Intensity on A Daily Basis	*A Comparison of Linear and Daily Undulating Periodization Programs with Equated Volume and Intensity for Strength*	Traditional Undulating (20)	St: Bench press, Leg Press	M - 21	Recreational Active (trained)	12 weeks: 3x/wk (40 mins)	St: Und>Trad
Channell et al., 2008 Compare the Effects of Olympic Lifts with Those of Power Lifts on Vertical Jump Improvement in Male High School Athletes	*Effects of Olympic Resistance Training on Vertical Jump Improvement in High School Boys*	Traditional Control (16)	P: Vertical Jump	M - 15.9	HS football - Recreational (trained)	8 weeks: 3x/wk	P: Trad>Con
Behringer et al., 2013 Investigate the Transferability of Effects of Two Different Types of Resistance Training on the Average Vsub and Maximum Velocity Serves in Youth Tennis Players	*Effect of Two Different Resistance Training Programs on Mean Tennis Serve Velocity in Adolescents*	Traditional Plyometric Control (36)	St: 10 RM Leg Press, 10 RM Chest Press, 10 RM Pull down Machine	M - 15.03	Junior Tennis Players (untrained)	8 weeks: 2x/wk	St: Trad>Plyo
Faigennbaum et al., 2001 Examine the Effects of 4 Different Resistance Training Protocols on Upper Body Performance Adaptations in Healthy Children	*Effects of Different Resistance Training Protocols on Upper Body Strength and Endurance Development in Children*	Traditional Control (17)	St: 1 RM Chest Press	Mixed - 8.1	Recreational Kids (untrained)	8 weeks: 2x/wk	St: Trad>Con
Faigennbaum et al., 1999 Effects of Low Repetition Heavy Resistance and High Repetition Moderate Resistance Program On Muscular Strength And Muscular Endurance In Children	*The Effects of Different Resistance Protocols On Muscular Strength and Endurance Development In Children*	Traditional Control (17)	St: 1 RM Chest Press. 1 RM Leg Extension	Mixed - 8.1	Recreational Kids (untrained)	8 weeks: 2x/wk	St: Trad>Con
Flanagan et al., 2002 Determine the Effect of Strength Training On Children and The Effects of Different Strength Training Modes On The Actual Performance Outcomes	*Effects of Two Different Strength Training Modes on Motor Performance in Children*	Traditional Control (28)	Sp: Shuttle Run P: Long Jump	Mixed - 8.5	Grade School Children (untrained)	10 weeks: 2x/wk	St: Trad>Con
Hammami et al., 2018 Compare 2 Types of ST Aimed at Developing Muscle Force, Explosiveness, and Muscle Power Measuring Sprint, RCOD, and Vertical Jump Performance	*The Effect of Standard Strength Training vs Contrast Strength Training on the Development of Sprint, Agility, Repeated Change of Direction and Jump in Junior Male Soccer Players*	Traditional Control (28)	Sp: 10m Run, 20m Run	M - 16	Youth Soccer Players (n/a)	8 weeks: 2x/wk (45mins)	St: Trad>Con

Study (Author & Outcome Measure)	Article name	Group Comparison (n)	Outcome measure	Gender/ Age (mean)	Training Status/RT Experience	Training Period Specifics	Outcome/ Conclusion
Lloyd et al., 2016 Examine the Effects of Different Resistance Training Programs On Measures Of Sprinting And Jumping. Pre- and post-PHV Male Youth	*Changes in Sprint and Jump Performance After Traditional, Plyometric and Combined Resistance Training in Male Youth Pre- and Post-Peak Height Velocity*	Traditional Plyo Control (80)	Sp: 10m Run, 20m Run P: Squat Jump	M - 14	Recreational Kids (untrained)	6 weeks: 2x/wk (60 mins)	St: Trad>Plyo P: Trad=Plyo
McKinlay et al., 2018 Effect Of 8-Weeks Of Training On Muscle Strength, Neuromuscular Function and Jump Performance Compared With No Added Training in Young Male Soccer Players	*Effects of Plyometric and Resistance Training on Muscle Strength and Neuromuscular Function in Young Adolescent Soccer Players*	Traditional Plyometric Control (41)	P: Squat Jump, CMJ	M - 12	Competitive Youth (untrained)	8 weeks: 2x/wk (30 mins)	P: Trad>Con, Plyo>Trad
Negra et al., 2016 Whether A 12 Week RT and PT program Will Enhance Explosive Actions Of Prepubertal Soccer Players And The Adequate Time Needed To Stimulate Improvement	*Effectiveness and Time-Course Adaption of Resistance Training vs. Plyometric Training In Prepubertal Soccer Players*	Traditional Plyometric Control (34)	St: Half squat Sp: 20 m Run, Illinois COD test P: SJ, CMJ, Multiple 5 bounds (MB5), SLJ	M - 12.8	Youth Soccer (trained)	12 weeks: 2x/wk (30-45 mins)	St: Trad>Plyo Sp: Trad>Plyo P: Trad>Plyo
Harries et al., 2015 Compare The Effectiveness of Two Resistance Training Progressions on Back Squat and Bench Press Performance Following 12 weeks of RT Programs In Rugby Players	*Comparison of Resistance Training Progression Models on Maximal Strength in Sub-Elite Adolescent rugby union players*	Traditional Undulating Control (26)	St: Box Squat, Bench Press	M - 16.9	Elite Rugby Player (trained)	12 weeks: 2x/wk (60 mins)	St: Trad=Und
Bartolomei et al., 2014 The Effect of The Traditional vs Block Periodization On Maximal Strength and Power In Highly Trained Subjects	*A Comparison of Traditional and Block Periodized Strength Training Programs in Trained Athletes*	Traditional Undulating (24)	St: Bench Press P: Squat Jump, CMJ	M - 22.5	T&F Thrower (trained)	15 weeks: 4x/wk	St: Trad=Und P: Trad=Und
Ozbar et al., 2014 8 week Low-Frequency, High-Volume and Low-Intensity Plyometric Training, Will Increase Jumps & Sprint Performance In Soccer Players	*The Effects of an 8-week Plyometric Training on Leg power, Jump and Sprint Performance in Female Soccer Players*	Plyometric Control (18)	Sp: 20m Run P: Squat Jump, CMJ, Dominant Leg Triple Jump, Non-dominant Leg Triple Jump	F - 18.4	Soccer Players (trained)	15 weeks: 4x/wk	Sp: Plyo>Con P: Plyo>Con
Chaouachi et al., 2014 The Effectiveness of Plyometric Only With Balance And Plyometric Training On Balance And Power Measures In Children	*The Combination of Plyometric and Balance Training Improves Sprint and Shuttle Run Performance More Often Than Plyometric-Only Training With Children*	Plyometric Control (28)	St: 1RM leg press Sp: 10m Run, 30m Run P: SLJ, CMJ	M - 13.6	Recreational Children (untrained)	8 weeks: 3x/wk	St: Plyo>Con Sp: Plyo>Con P: Plyo>Con

Study (Author & Outcome Measure)	Article name	Group Comparison (n)	Outcome measure	Gender/ Age (mean)	Training Status/RT Experience	Training Period Specifics	Outcome/Conclusion
Chelly et al., 2010 Whether 8 weeks of Biweekly Plyometric Training Will Enhance Physical Performance Relative To Their In-Season Training	*Effects of In-Season Short-Term Plyometric Training Program on Leg Power, Jump- and Sprint Performance of Soccer Players*	Plyometric Control (23)	P: SLJ, CMJ	M - 19	Regional Soccer Players (trained)	8 weeks: 2x/wk	P: Plyo>Con
Moraes et al., 2013 Compare NP Training and DNLP Training On Strength, Power, And Flexibility In Untrained Apparently Healthy Adolescents	*Effects on Strength, Power, and Flexibility in Adolescents of Nonperiodized vs. Daily Nonlinear Periodized Weight Training*	Traditional Undulating Control (38)	P: SLJ, CMJ	M - 15.5	Recreational School-Aged Children (trained)	12 weeks: 2x/wk	P: Trad=Und
Baker et al., 1994 To Compare The Effectiveness of Three Strength Training Structures on Maximal Strength and Vertical Jump in Trained Males	*Periodization: The Effect on Strength of Manipulating Volume and Intensity*	Traditional Undulating (13)	P: VJ	M - 20	Recreational Athletes (trained)	12 weeks: 3x/wk	P: Trad=Und

CHAPTER 2

INTRODUCTION

The National Federation of State High Schools Associations (NFHS) participation survey for the 2016-2017 school year states that over 7.9 million high school students participated in some sport, an increase of 8.5% over the last 10 years[1]. The vast increase in sport participation amongst adolescents can be attributed to several reasons such as aspirations to compete as a collegiate athlete or carry professional status. Sports participation in youth athletes creates excessive stress and overload on the body can lead to injury and potential long term growth disturbances[2]. Consequently, as sports participation amongst youth increases, risk of burnout increases[2]. The physical and emotional stress, unrealistic parental expectations as well as exploitations or elite youth sport exposure can contribute to negative psychological consequences for youth athletes[2]. Over the past decade there has been an overwhelming trend for youth athletes to participate in athletic performance (resistance) training. Research has shown that resistance training can improve sports performance, rehabilitate and prevent injury, and enhance long term health in adolescent athletes[3]. Additionally, research studies confirm that resistance training can have an effect on body composition, lipid profiles, resting metabolic rate, and blood pressure[4]. Resistance training also supports motor skills acquisition and neuromuscular learning [3,5]. Resistance training programs can include body weight, free weights, elastic tubing or weight machines exercises and movement skills[6,7]. It is important to know that research supports avoidance of early sports specialization but rather advocates for long term athlete development[2,6]. Long term athlete development (LTAD) offers a positive framework to develop physical literacy[6].

Knowing the demands placed on the athlete as well as understanding an athletes' eagerness to compete at the highest level individually, it is paramount that strength and conditioning professionals prescribe training programs that maximizing performance outcome measurements in youth athletes. Performance outcome measurements, along with various training periodization protocols, have been studied in adult men and women, competitive and recreational athletes as well as the aging population. Although, research has addressed performance outcome measurements in the aforementioned group, the research regarding youth is limited. One of the main goals of a strength and conditioning professional is to obtain the greatest performance outcome measure by having a strength training program that contains variations on volume, intensity, and exercise selection. In terms of exercise, volume is measured by number of sets, reps, or exercises performed throughout the entirety of the workout and intensity refers to the amount of work required to complete the activity such as amount of weight lifted throughout session.

Periodization is a training scheme where planned variations in training variables are manipulated in a manner that increases the ability of a person to achieve specific performance goals[8]. An analysis to determine what specific training methodology traditional periodization, undulating periodization, or plyometric training has greater influence on performance outcomes in youth athletes is essential for further exercise prescription in youth athletes. The findings of the current meta-analysis will help exercise training professionals provide recommendation on appropriate resistance training for youth athletes with the purpose of maximal performance.

Training periodization can be divided into cycles of training. Macrocycles would typically incorporate 52 weeks or an annual comprehensive program. Mesocycles vary and can last up to 3-4 months and incorporate several microcycles. Microcycles are the shortest of cycles lasting several weeks at a time. Periodization is also based on the overload principle and attempts to maximize the use of the physical stress and recovery time by manipulating volume and intensity to facilitate important neuromuscular adaptations[8]. Training variables can be defined as the number of sets and repetitions, exercise selection, the order in which the exercises are performed, load of the weight being lifted, and even the rest intervals between reps or set. As stated earlier, three of the leading programs for resistance training are traditional periodization, undulating periodization or plyometric training. Traditional periodization, also known as traditional periodization typically starts with high-volume, low-intensity training and progresses to low-volume, high-intensity strength training[9,10]. If traditional periodization is followed over the an entire year, the training phases/cycles will be repeated[11]. Traditional periodization training cycles tend to last from 4-6 weeks. A main goal of traditional periodization is to peak at a planned time or maximize strength and power after the last training cycle typically referred to as the power phase[11,12]. Undulating periodization relies more on irregular manipulation of volume and intensity across the training cycle with short period of high-volume training alternated with short periods of high-intensity training[8]. Changes with undulating periodization can be daily, weekly or even biweekly. The key goal of undulating periodization is to maintain high performance levels during training. The high performance maintenance is obtained by programming volume and intensity variations frequently[13]. The other training methodology that is also prominent in strength training is plyometric training, also known as countermovement jump training which incorporates body weight to perform hopping, jumping and skipping activities[14].

Plyometric training integrates the stretch shortening cycle (SSC) of the muscle and stimulation of the muscle spindles during eccentric loading to elicit greater muscle power production during the concentric muscle contraction. Through research, plyometrics performed by athletes have shown to provide benefits as neuromuscular function, increased power production, increased bone mineral density, and decreased incidence of injury[14]. A main outcome of plyometric training is to generate an elevated strength and power production value in a reduced time and increase the power of subsequent movements using both natural elastic components of muscle and tendon and the stretch reflex[14,15].

The long-term goals for this systematic review are to understand if a particular training methodology has a greater impact on performance outcomes compared to another training programs. Our primary objective is to investigate the efficacy between traditional periodization, undulating periodization, plyometric training, and/or a control group and its effect on performance outcomes in youth athletes. Once we have collected and analyzed the data, we will have a better understanding of which particular strength training methodology elicits greater strength gains and athletic performance outcomes. This particular goal of this study will be reached by having these specific aims: (1) to determine if youth athletes who participate in a traditional periodization programming experience greater improvements in performance outcomes when compared to youth athletes who participate in an undulating periodization programs, (2) to determine if youth athletes who participate in a traditional periodization programming experience greater improvements in performance outcomes when compared to youth athletes who participate in a plyometric programs, and (3) to determine if youth athletes who participate in an undulating periodization program experience greater improvements in performance outcomes when compared to youth athletes who participate in a plyometric-only programs. After a thorough examination of these specific aims, we can identify the type of training programs produces the greatest benefit in performance outcomes in youth athletes. With this data exercise professionals will be able to make scientifically based decisions on the exercise training methodology that is most effective in performance outcome goals for individual in specific sports.

CHAPTER 3

METHODS

This review was guided by a comprehensive search of PubMed and the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISM) Statement. The review was conducted over an 8-month process with restrictions on article search dating back to January 2007 and cutoff date being January 2019. The key terms used were children, youth, sport, resistance training, strength training, plyometric training, and exercise. Inclusion criteria included: (1) studies involved case verse control comparison, (2) studies compared traditional periodization, undulating periodization, or plyometric training to an alternative training periodization methodology, (3) studies included quantitative data on strength and power performance measures and plyometric performance measures, (4) participants of study must be physically active, (5) studies were peer reviewed and written in English, (6) data was reported in means and standard deviations for all training periodization methodology at post-test. Training experience was not a restriction placed on the data collection. Exclusion criteria were as follows: (1) studies that had jump training was incorporated into traditional periodization or undulating periodization protocol, (2) studies that did not have a control group, (3) studies that did not report means and standard deviation values for strength and plyometric performance measures.

Inclusion Criteria

Studies investigating traditional strength/resistance periodization, undulating periodization, or plyometric-only training in adolescent and youth kids were included in the review if they fulfilled the following selection criteria: the study (1) was a randomized controlled trial or a controlled trial; (2) measured pre- and post-training strength such as maximal loads (i.e., 1 repetition maximum: (1RM) or leg extension or flexion, bench press, shoulder press, chin ups), plyometric-related [i.e., countermovement jump (CMJ), horizontal or standing long jump (SLJ)] or speed-related (e.g., 10-m sprint time); (3) training duration was greater than or equal to 4 weeks; (4) used healthy, untrained (i.e., physical education classes and/or no specific sport) or trained (i.e., youth athletes from different sports) participants; (5) was written in English and published prior to January 2019; and (6) was published in a peer-reviewed journal (abstracts and unpublished studies were excluded). Studies were excluded if precise means and standard deviations, or effect sizes were not available or if the training study combined both strength, power and plyometric exercises.

Coding of Variables	
Strength	Squat, Deadlift, Bench Press, Leg Press/Extension, Shoulder Press, Bicep Curls
Power	Vertical Jump, Countermovement Jump, Peak Rate of Force Development, Standing Long Jump, Multiple 5 Bound, Triple Jump
Speed	10-meter run, 20-meter run, Shuttle Run,

Data Extraction

The extraction of data for gathering articles was performed by two examiners. The first reviewer collected that data before the second reviewer analyzed the study data for accuracy and that the article met inclusion criteria. Power, strength, and speed performance outcomes were the main focus of the data extraction. Means and standard deviations were also extracted and used for consistency. Fixed effect sizes were calculated for all performance outcome.

Statistical Analysis

To determine the effects of various resistance training protocols on performance outcomes in youth athletes, the effect size was also calculated. Statistical analyses were performed using MedCalc for Windows, version 16.4 (MedCalc Software, Ostend, Belgium) The effect size estimates were computed as standardized mean differences (SMD) of intervention and control group with their 95% confidence intervals (CI) and are presented in forest plots[16,17]. The SMD was considered statistically significant if the value 0 was not within the 95% CI. The marker size is relative to study weight and the pooled effects are represented using a diamond in which the location represents the effect size (ES) and the width reflects the precision of the estimate. The magnitudes of the effect sizes were considered small (>0.2), medium/moderate (>0.5), or large (>0.8)[18]. Statistical heterogeneity in this meta–analysis was assessed using Q, degrees of freedom, and p-value ($p < 0.05$) calculations for statistical significance.

CHAPTER 4

RESULTS

Strength: The effect sizes indicate traditional periodization training significantly improved strength performance outcomes when compared to control group (i.e. non-resistance training) ($p < 0.01$) undulating periodization ($p < 0.01$) and plyometric training ($p < 0.03$) (Figures 2, 3, and 4, respectively). The fixed effect size calculations for traditional periodization and strength performance outcome were large when compared with a control group (1.19), small fixed effect size when compared to undulating periodization (0.22), and a medium fixed effect size when compared to plyometric training (-0.59). Undulating periodization training significant ($p <.0.01$) increased strength performance outcomes when compared to control group with a large fixed effect size (1.44) (Figure 5). There is no statistical significance ($p = 0.28$) and a small effect size (0.48) for performance outcomes for strength when comparing plyometric training and control group (Figure 6). There were no studies included in this review that compared undulating periodization to plyometric training for strength performance outcomes. More research needs to be conducted to provide practitioners guidance on optimal performance methodology.

Power: Power performance outcome significantly ($p < 0.01$) improved when using traditional periodization programs with a medium fixed effect size (0.66) when compared to a control group (Figure 7). There was a statistically significant ($p < 0.03$) but a small fixed effect size (-0.08) when comparing power performance outcomes for traditional periodization verse undulating periodization (Figure 8), and no significance statistically ($p < 0.29$) when comparing traditional periodization versus plyometric training on power performance outcomes and a small fixed effect size (0.13) (Figure 9). There was no statistical significance ($p = 0.16$) on power performance outcomes when comparing undulating periodization to control group with a small fixed effect size (0.47) (Figure 10). Statistical significance ($p = 0.01$) and a large fixed effect size (0.87) was shown when comparing plyometric training and control group on power performance outcomes (Figure 11). Unfortunately, there were no articles included in this review that compared undulating periodization to plyometric training on power performance outcomes which warrants further research.

Speed: Traditional periodization was showing to significantly ($p<0.01$) improve speed performance outcomes and had a medium fixed effect size (-0.56) when compared to a control group (Figure 12). There was no statistically significant difference ($p <0.13$) when traditional periodization is compared to plyometric training speed performance outcomes with a small fixed effect size (0.14) (Figure 13). Furthermore, plyometric training showed statistical significance ($p = 0.01$) in speed performance outcomes and a small fixed effect size (-0.36) when compared to control group (Figure 14). There were no articles that compared traditional and undulating periodization or undulating and plyometric on speed performance outcomes that fit our inclusion criteria. More research needs to be conducted on these specific training protocols to provide a clarity as to which training methods provides superior benefits for speed outcomes.

CHAPTER 5

DISCUSSION

Over the years data from the NFHS has shown a steady increase in youth (≤ 18 years old) sport participation which subsequently has focused more attention and emphasis on sports performance training. The goal of sports performance training is to enhance the performance outcomes that are required to participate in a particular sport[5]. From a recent meta-analysis[19], it is clear that resistance and plyometric training can have a positive effect on physical performance outcomes for squat, vertical jump and sprinting in youth[19]. While not a primary objective of the present study, we did show the incorporation of traditional and undulating periodization into a regular sports training program significantly improved strength, speed and power, whereas plyometric only increased speed and power to a greater extent than participating in practice alone.

This current meta-analysis identified 23 studies that compared traditional periodization, undulating periodization or plyometric training to each other or a control group on sport performance outcomes in youth athletes that fit within the inclusion criteria. Based off the data extracted for this current meta-analysis, evidence shows traditional resistance training periodization provides greater improvements on strength performance outcome when compared to undulating periodization. There was a small fixed effect size reported from this comparison. This current meta-analysis included participants that were untrained and had no resistance training 6 months prior to intervention as well as participants that were considered to be trained. Additionally, most studies comparing traditional periodization to undulating periodization involved untrained recreational athletes older than 16 years old. The results suggest it is more advantageous to begin a training method focused on a high-volume, low-intensity training scheme, then shift towards a low-volume, high-intensity training scheme progressing through the mesocycles of the annual plan with regards to untrained athletes. Harries et al. conducted a 12 week training program of adolescent rugby players and reported increased lower body strength when following an undulating periodization method yet also showed traditional periodization produced greater lasting improvements on upper body strength, but overall there was no significant difference between traditional and undulating periodization[9]. Moras et al. study showed increases in upper body and lower body strength when using traditional periodization or undulating periodization with no significant difference between the training methods[20]. A 12-week study by Apel et al. in recreationally active adults suggest that traditional periodization may be more effective at increasing strength while maintaining weight when compared to undulating periodization[8]. Improvements in strength performance outcomes can initially been seen through neural adaptations of central nervous system rather than muscular hypertrophy in untrained individuals[5,21]. Neural adaptations are evident because of increased motor unit activation, improved functioning of the stretch shortening cycle (SSC), and improved rate of force development (RFD)[5]. The progressive overload principle of strength training states that the body must be forced to makes adaptations to unfamiliar stress being placed upon it. A byproduct of the progressive overload principle is increased maximal strength. Increased neuromuscular functioning translates as increases in overall muscular strength, which may be why this current meta-analysis suggest that traditional periodization provides optimal performance benefits in untrained youth athletes when compared to undulating periodization.

This current meta-analysis showed a small effect size in improved power performance outcomes in youth athletes for traditional periodization compared to undulating periodization. The resistance training interventions assessed in this review were short in duration with only one study lasting longer than 12 weeks. The participants involved varied between recreational or trained individuals, and all participants were 16 years old or greater. Although the review is supposed to examine adolescents, an untrained individual's trainability or ability to improve is similar to that of an adolescent. Current research is conflicting regarding whether traditional periodization or undulating periodization provides greater improvements sports performance outcomes although both yield positive benefit.

Studies in the literature indicate that traditional periodization is superior to undulating periodization for improving power. Harries et al. reported that a 12 week traditional periodized resistance training had no significant difference when compared to undulating periodization on power performance outcomes such as the vertical jump in rugby players[9]. Whereas, a 15-week training study of adult recreationally active males by Bartolomei et al. suggested that undulating periodization exhibited greater upper body power performance outcomes when compared to traditional periodization[22]. Power is an expression of force (strength) and velocity. Strength in adolescents is initially translated through neuromuscular trainability and cognitive development which novice and experienced individual responded similarly to resistance training. We also see strength increases through muscular hypertrophy for adults which is not seen in prepubescent individuals. Though this current meta-analysis shows traditional periodization to be superior to undulating periodization for improvements in sport performance outcomes;

the lack of overall physical development seen from short term interventions make it difficult to formulate educated conclusions regarding the long-term effectiveness of traditional periodization or undulating periodization on performance outcomes.

Further research is needed comparing traditional and undulating periodization training methods effectiveness on enhancing power performance outcomes in youth athletes which would improve the quality of review. Unfortunately, there were no studies that fit the inclusion criteria comparing the efficacy between traditional periodization and undulating periodization on the effects of speed performance outcome in youth athletes. Additional research is needed comparing the traditional periodization and undulating periodization and the lasting effects on all sport performance outcomes in youth athletes.

The second specific aim of this review was to determine if youth athletes who participate in a traditional periodization programming experience greater improvement in performance outcomes when compared to youth athletes who participate in a plyometric training only. The main findings are as follows; traditional periodization is superior to plyometric training at providing lasting impact on strength in sports performance outcomes in youth athletes, but not significantly different than plyometric training at providing lasting impact on power or speed sport performance outcomes in youth athletes. The data from this current meta-analysis shows that there is evidence that traditional periodization provides greater improvements in strength performance outcomes in youth athletes than plyometric training alone. The current meta-analysis had 3 articles that compared traditional periodization, plyometric training, or a control group on strength performance outcomes in adolescents. An 8-week study conducted by Behringer et al. that examined the difference between resistance training, plyometric training and a control group saw that both training methods provide increases in strength with strength training being slightly greater in adolescent tennis players[23]. Known as the principle of specificity, the specific adaptations to imposed demands principle simply states that when placed under biomechanical or physiological stress as human we can adapt to the demands placed on us[24]. The NSCA position statement regarding resistance training in children and youth says that resistance training can promote increases in strength above and beyond growth and maturation[21]. Research also shows that gains in strength for preadolescents can be seen through not only neural adaptation but increases in bone mineral density, greater stretch reflex, and enhancement of motor such as control of the golgi tendon apparatus[21,25,26]. The General Adaptation Syndrome (GAS) made famous by Hanz Selye states that the stress of exercise will initially decrease performance followed by an adaptation of supercompensation typically greater than previous physical functioning[27]. The magnitude of stress (volume, intensity or frequency) must be gradually increased for improvements of the biological systems to occur which then the body goes through an acclamation phase which is the progressive overload principle. Though adaptations on strength performance outcomes from plyometric training can be seen in adolescents; stress can be applied at a greater magnitude with traditional periodization training and elicit greater improvements which is presented from the findings of this review.

Furthermore, the second main finding of this particular specific aim was that no significant difference was found on lasting improvements of power outcomes on adolescent athletes for traditional periodization when compared to plyometric training with fixed effect size being small. The training programs investigated for this specific outcome were mixed with novice and experienced individuals <16 and >16 years old and did not show bias towards either traditional periodization or plyometric training. The main focus of a plyometric exercise is to use stored (potential) energy created by muscle contractions to exert maximal force over the shortest period of time. Lloyd et al. compared traditional training, plyometric training, combined training and a control group over 6 weeks found that plyometric training elicited greater improvements on power in untrained adolescents[28]. Negra et al. studied youth soccer players during a 12 week training program and reported that traditional periodization was more beneficial on power outcomes when compared to plyometric training[29]. Power can be expressed in terms of force (mass times acceleration) and velocity (displacement divided by time). These two variables, force and velocity, are directly proportional to each other. As previously mentioned, plyometric exercises are utilized because of the high velocity intent in which these exercises are performed and the effect plyometrics can induce on the CNS. At a young age the trainability of the nervous system is abundant and the high neural developments and adaptations that are seen from plyometric training may be synergistic with maturation and growth[28,30]. The data extracted from this current meta-analysis shows that muscular strength can have an effect on force application as well as velocity and can affect power performance outcomes especially in adolescents. Further research needs to be conducted on provide better rationale for one training method over the other.

Finally, traditional periodization did not have any significant difference when compared to plyometric training on speed performance outcomes in youth athletes. The participants in these articles analyzed in this review were trained and untrained adolescents. One study in this current meta-analysis looked at different resistance training and plyometric protocols on adolescents and its effect on sprint times over a six-week period (REF). In this current meta-analysis, plyometric training had a greater effect than resistance training at improving sprint performance[28]. Negra et al. conducted a 12 week study to compare competitively trained youth soccer players had found that resistance training showed greater improvements on 20-m sprint time than plyometric training only[29]. In agreement with aforementioned information, the principle of specificity suggests that adaptations to training are predicated on the mode, duration and frequency of the intervention[31]. It also suggests that training induced adaptations only happen within trained musculature and training closely mimic desired outcome for outcome enhancement. Speed can be enhanced by several components such as starting strength, acceleration and force production, muscle and tendon elasticity, stride length and stride frequency. Knowing that there are several factors involved in speed makes it difficult to pinpoint which factors have greater magnitude. An increase in strength can provide the ability to produce greater force to overcome starting inertia as well as force production on ground contact. Running mechanics and plyometric are modes that directly mimic sprinting which is the gold standard measurement of speed performance outcome. More research needs to be conducted regarding the influence resistance training (i.e. traditional and undulating periodization) and plyometric training have on adolescents speed performance outcomes.

The last specific aim of this review was to determine if youth athletes who participate in an undulating periodization program experience greater improvement in performance outcomes when compared to youth athletes who participate in plyometric-only programs. To our knowledge there were no studies comparing undulating periodization to plyometric only training that fit our inclusion criteria specifically for this review.

In the current meta-analysis traditional periodization, undulating periodization and plyometric training were compared to a control group and showed statistical significance at improving sports performance outcomes in youth athletes. Traditional periodization and undulating periodization had significant improvement on strength performance outcome in youth athletes while plyometric training did not show an improvement in strength when compared to a control group. Undulating periodization had a greater effect size on strength performance outcome when compared to a control group than traditional periodization. This may suggest that its variations in stress can have a greater effect on the accumulation phase of physical resistance training and enhance strength gains. Yet as stated earlier, traditional periodization is far superior to undulating periodization in direct comparison. A recent meta-analysis looked at resistance training to improve strength and power in adolescent athletes and saw that despite significant effects seen in adult athletes, greater adaptations in motor performance were observed in children, untrained participants and non-athletes[32]. Strength gains in children and adolescent are initially seen through neurocognitive development and neural adaptations. Research also demonstrates the process of "synergistic adaptation," which refers to the link between specific adaptations of an imposed training demand with concomitant growth and maturity-related adaptations[28].

In conclusion, child participation in sports both recreational and competitively continues to increase with more focus geared towards sport performance over the past decades. The ultimate purpose of sports performance training goals is to improve the athletic performance attributes such as speed, power and strength. This review revealed that traditional periodization had greater lasting effects on sports performance outcomes when compared to undulating periodization for strength and power. The progressive overload principle and maximum strength goal of traditional periodization elicits greater performance outcomes with a novice individual. Traditional periodization when compared to plyometric training showed greater lasting effects on strength performance outcomes. Periodization refers to planned changes in the acute training program variables such as number of sets and repetitions, rest periods, training intensity and training volume to bring about continued and optimal fitness gains[11,33]. Resistance training has shown to improve bone mineral density, neural adaptations, muscle mass and muscular strength[7,34,35]. Our research shows plyometric training can increase power and speed, vertical jump height, rate of force development and it seems to have applicability towards power production and speed performance outcomes more so than strength performance outcomes in youth athletes. This applicability or specificity of training is because the movements of plyometric can mimic speed outcomes and the application of horizontal forces when sprinting. Limitations to this systematic review and meta-analysis could potentially be reviewer bias, the lack of adolescent articles that fit inclusion criteria for strength performance outcome, limited articles demographics, confusion of training method terminology, sample size of articles reviewed, or quality of resistance training program. This meta-analysis supports the hypothesis that a comprehensive annual training program that incorporates plyometric training into a traditional resistance training may elicit the greatest benefit and improvement of sport performance outcomes in youth athletes.

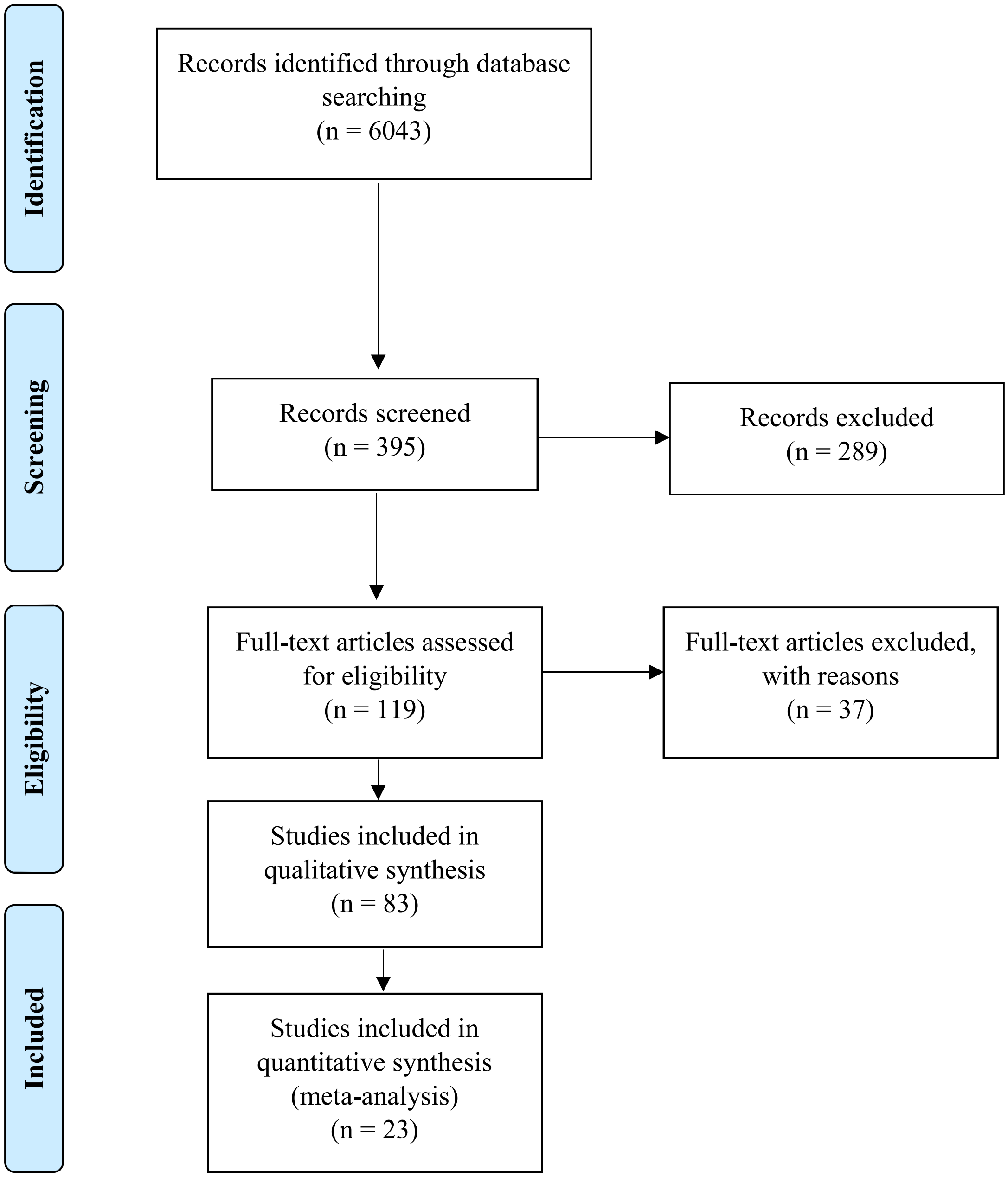
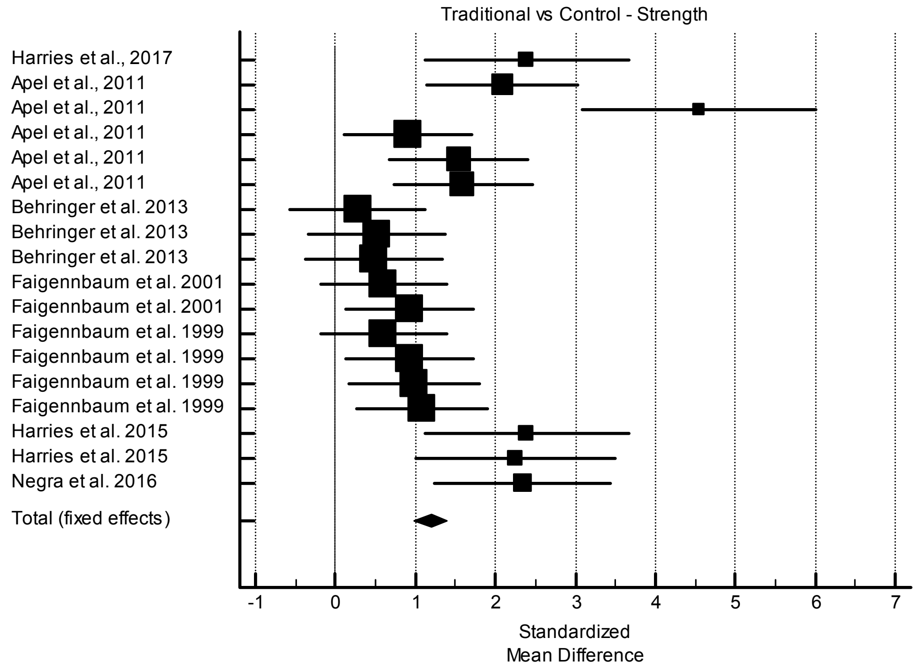


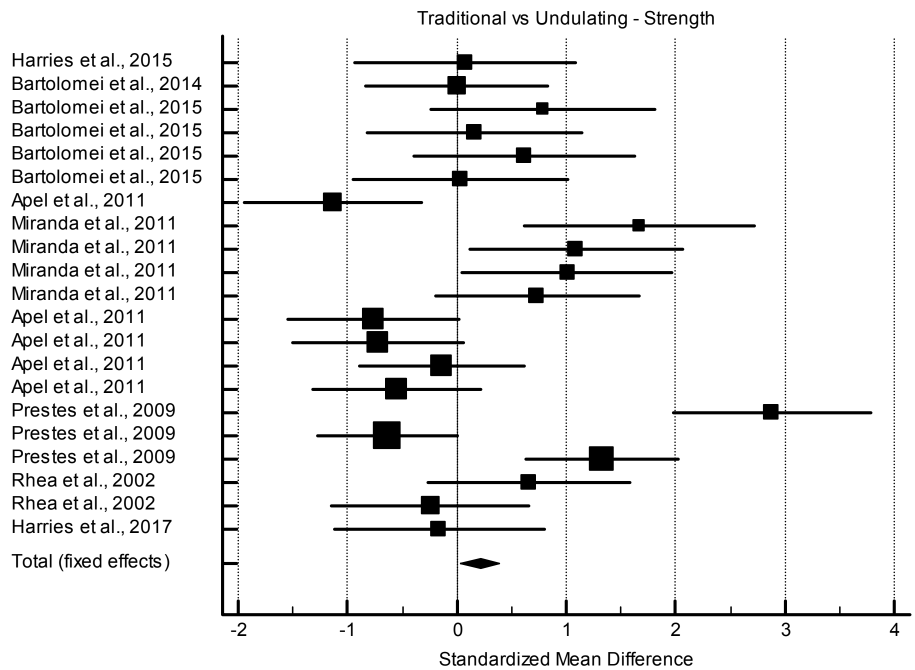
Fig 1: Preferred Reporting Items for Meta-Analysis (PRISM) Flow Chart



Study	Weight (%)	SMD	SE	95% CI
Harries et al., 2017	2.94	2.394	0.603	1.116 to 3.672
Apel et al., 2011	5.03	2.087	0.461	1.140 to 3.035
Apel et al., 2011	2.12	4.553	0.711	3.093 to 6.014
Apel et al., 2011	7.16	0.903	0.386	0.109 to 1.697
Apel et al., 2011	6.02	1.549	0.421	0.683 to 2.415
Apel et al., 2011	5.93	1.597	0.425	0.725 to 2.470
Behringer et al. 2013	6.44	0.283	0.408	-0.564 to 1.131
Behringer et al. 2013	6.28	0.519	0.413	-0.339 to 1.377
Behringer et al. 2013	6.32	0.473	0.411	-0.383 to 1.328
Faigennbaum et al. 2001	7.23	0.604	0.384	-0.188 to 1.396
Faigennbaum et al. 2001	6.99	0.931	0.391	0.127 to 1.735
Faigennbaum et al. 1999	7.23	0.604	0.384	-0.188 to 1.396
Faigennbaum et al. 1999	6.99	0.931	0.391	0.127 to 1.735
Faigennbaum et al. 1999	6.73	0.983	0.399	0.162 to 1.804
Faigennbaum et al. 1999	6.75	1.082	0.398	0.264 to 1.900
Harries et al. 2015	2.94	2.394	0.603	1.116 to 3.672
Harries et al. 2015	3.11	2.246	0.587	1.002 to 3.489
Negra et al. 2016	3.80	2.343	0.530	1.240 to 3.446
Total (fixed effects) t=11.521, p<0.001	100.00	1.191	0.103	0.988 to 1.394

Test for heterogeneity: Q=60.8459; DF=17; $p<0.0001$; I^2=72.06%; 95% CI for I^2= 55.17 to 82.59

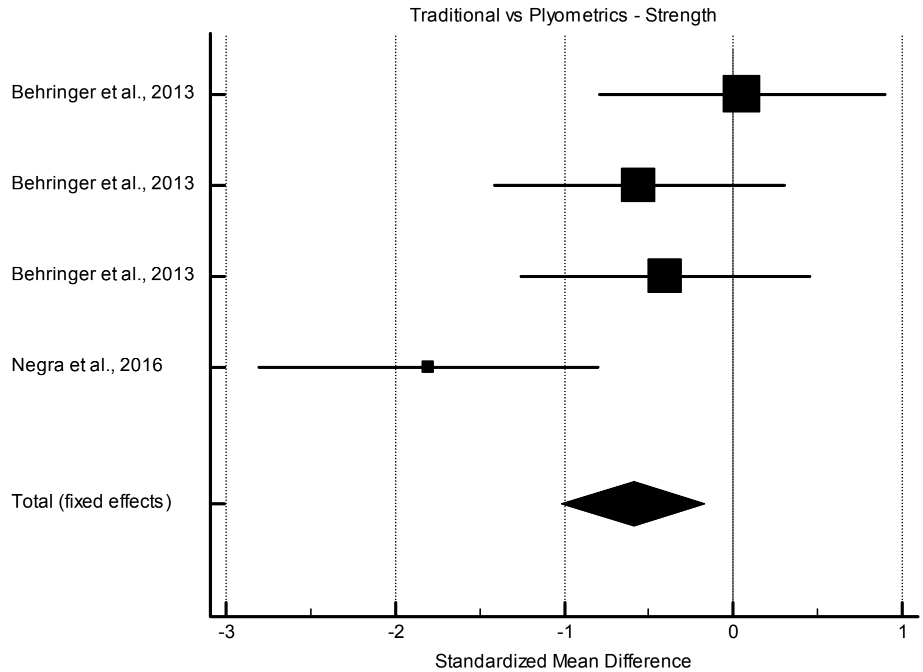
Figure 2. Forest Plot: Effects of Traditional Periodization vs Control Group on Strength Performance Outcomes. SMD: Standardized Mean Difference, CI: Confidence Interval, df: Degrees of Freedom, *p*: p-value



Study	Weight (%)	SMD	SE	95% CI
Harries et al., 2015	3.70	0.0771	0.473	-0.937 to 1.091
Bartolomei et al., 2014	5.17	0.000	0.400	-0.829 to 0.829
Bartolomei et al., 2015	3.58	0.792	0.481	-0.233 to 1.816
Bartolomei et al., 2015	3.87	0.161	0.462	-0.824 to 1.145
Bartolomei et al., 2015	3.70	0.612	0.473	-0.396 to 1.620
Bartolomei et al., 2015	3.89	0.0364	0.461	-0.947 to 1.019
Apel et al., 2011	5.25	-1.132	0.397	-1.947 to -0.316
Miranda et al., 2011	3.27	1.669	0.503	0.612 to 2.726
Miranda et al., 2011	3.88	1.092	0.462	0.122 to 2.062
Miranda et al., 2011	3.96	1.011	0.457	0.0505 to 1.971
Miranda et al., 2011	4.20	0.736	0.444	-0.197 to 1.668
Apel et al., 2011	5.70	-0.763	0.381	-1.546 to 0.0198
Apel et al., 2011	5.74	-0.721	0.379	-1.501 to 0.0585
Apel et al., 2011	6.13	-0.135	0.367	-0.890 to 0.620
Apel et al., 2011	5.90	-0.549	0.374	-1.318 to 0.221
Prestes et al., 2009	4.14	2.881	0.447	1.976 to 3.786
Prestes et al., 2009	8.18	-0.633	0.318	-1.276 to 0.0110
Prestes et al., 2009	6.99	1.332	0.344	0.635 to 2.028
Rhea et al., 2002	4.26	0.658	0.441	-0.268 to 1.584
Rhea et al., 2002	4.47	-0.242	0.430	-1.145 to 0.662
Harries et al., 2017	4.04	-0.159	0.452	-1.119 to 0.800
Total (fixed effects)	100.00	0.216	0.0909	0.0369 to 0.394
t=2.370; p=0.018				

Test for heterogeneity: Q=104.3634; DF = 20; p<0.0001; I^2=80.84%; 95% CI for I^2= 71.56 to 87.09

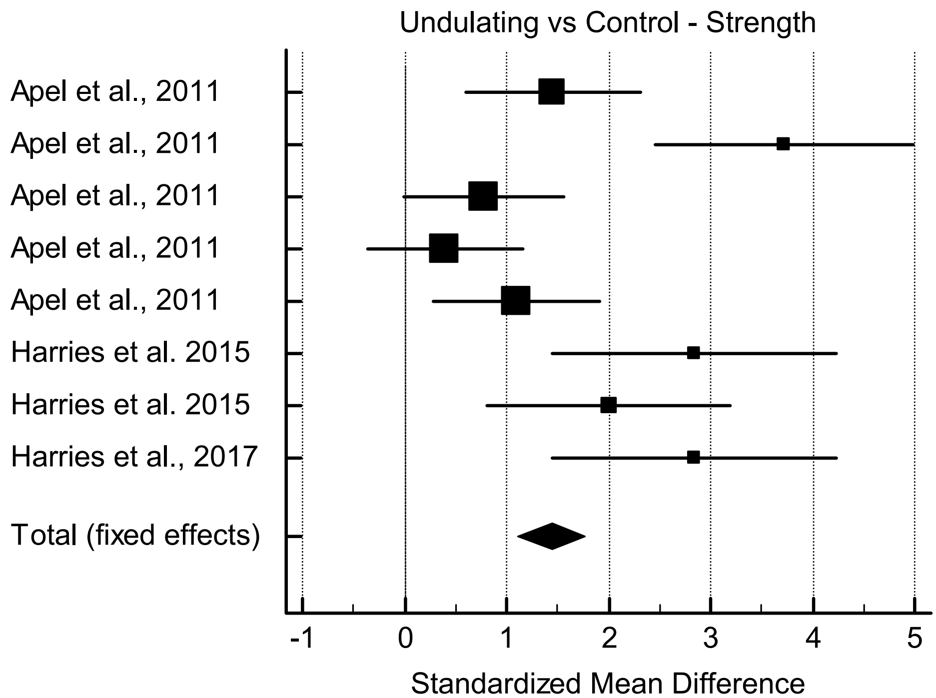
Figure 3. Forest Plot: Effects of Traditional Periodization vs Undulating Periodization on Strength Performance Outcomes. SMD: Standardized Mean Difference, CI: Confidence Interval, df: Degrees of Freedom, *p*: p-value



Study	Weight (%)	SMD	SE	95% CI
Behringer et al., 2013	13	0.0505	0.405	-0.793 to 0.894
Behringer et al., 2013	13	-0.555	0.414	-1.415 to 0.305
Behringer et al., 2013	13	-0.401	0.410	-1.253 to 0.451
Negra et al., 2016	11	-1.801	0.482	-2.803 to -0.798
Total (fixed effects)	50	-0.589	0.212	-1.011 to -0.168
t=-2.776; p=0.007				

Test for heterogeneity: Q=9.0256; DF = 3; $p<0.0290$; I^2=66.76; 95% CI for I^2= 2.84 to 88.63

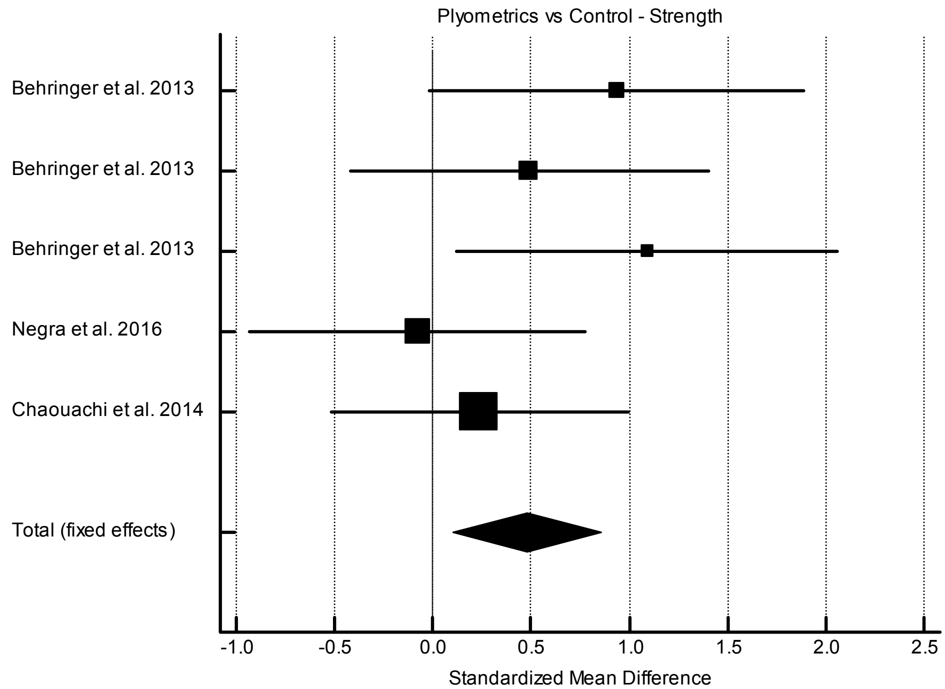
Figure 4. Effects of Traditional Periodization vs Plyometric Training on Strength Performance Outcomes. SMD: Standardized Mean Difference, CI: Confidence Interval, df: Degrees of Freedom, *p*: p-value



Study	Weight (%)	SMD	SE	95% CI
Apel et al., 2011	15.76	1.453	0.415	0.599 to 2.306
Apel et al., 2011	7.12	3.719	0.618	2.449 to 4.989
Apel et al., 2011	18.66	0.782	0.382	-0.00231 to 1.566
Apel et al., 2011	19.76	0.397	0.371	-0.365 to 1.159
Apel et al., 2011	17.41	1.094	0.395	0.282 to 1.906
Harries et al. 2015	6.34	2.842	0.655	1.455 to 4.230
Harries et al. 2015	8.61	2.004	0.562	0.813 to 3.195
Harries et al., 2017	6.35	2.839	0.654	1.452 to 4.226
Total (fixed effects)	100.00	1.441	0.165	1.116 to 1.766
t=8.746; p<0.001				

Test for heterogeneity: Q, 35.4378; DF,78; p<0.0001; I^2=80.25%; 95% CI for I^2= 61.77 to 89.80

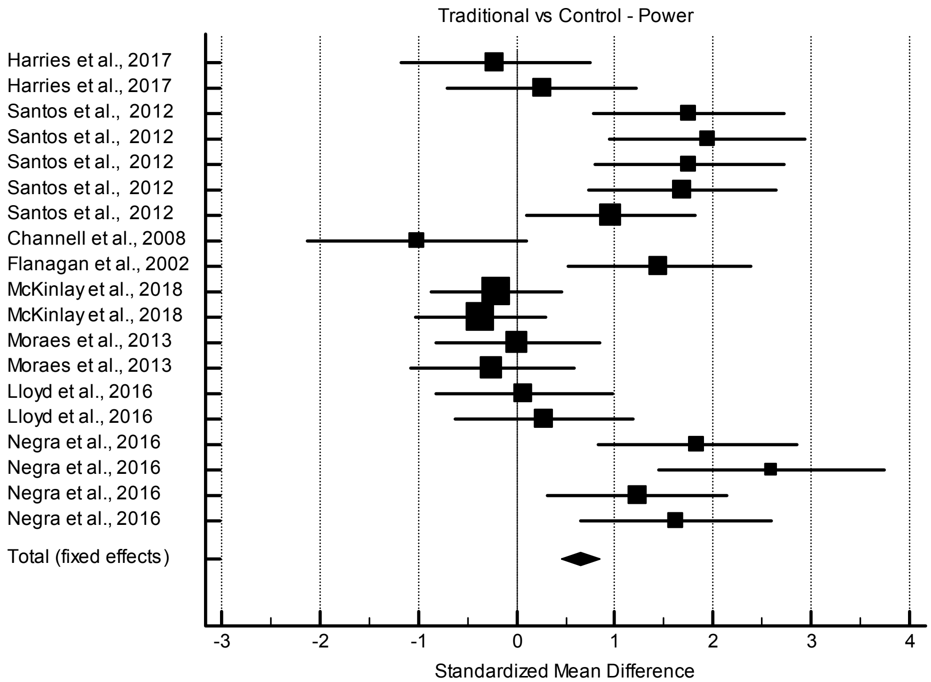
Figure 5. Forest Plot: Effects of Undulating Periodization vs Control Group on Strength Performance Outcomes. SMD: Standardized Mean Difference, CI: Confidence Interval, df: Degrees of Freedom, *p*: p-value



Study	Weight (%)	SMD	SE	95% CI
Behringer et al. 2013	17.30	0.935	0.453	-0.0166 to 1.887
Behringer et al. 2013	18.75	0.491	0.435	-0.423 to 1.406
Behringer et al. 2013	16.66	1.091	0.462	0.121 to 2.061
Negra et al. 2016	21.10	-0.0775	0.410	-0.933 to 0.778
Chaouachi et al. 2014	26.19	0.237	0.368	-0.520 to 0.994
Total (fixed effects)	100.00	0.481	0.188	0.108 to 0.855
t=2.555; p0.12				

Test for heterogeneity: Q=5.0401; DF=4; p=0.2832; I^2=20.64%; 95% CI for I^2= 0.00 to 66.28

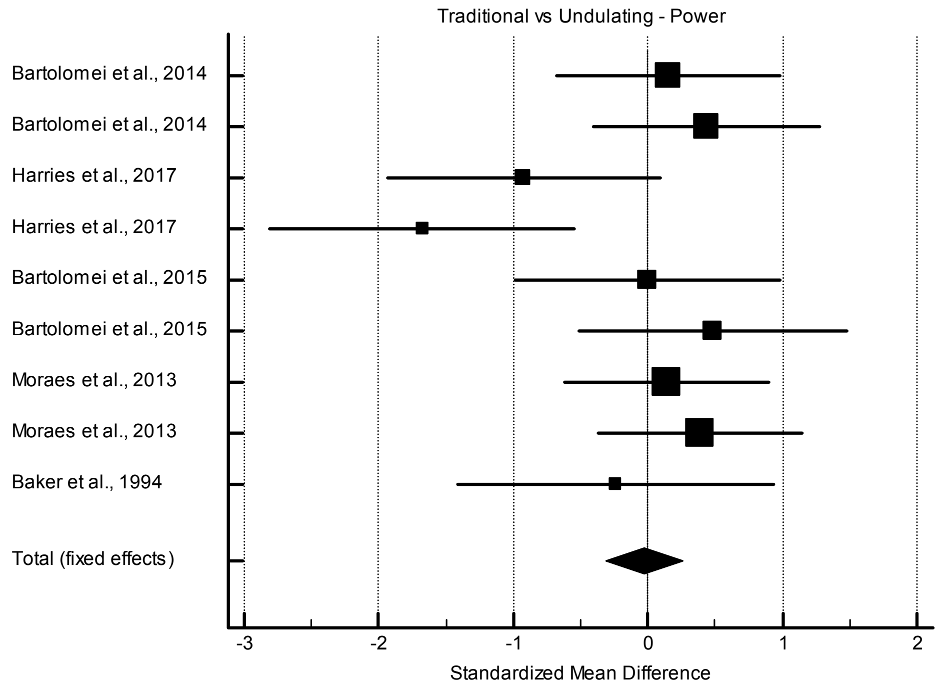
Figure 6. Forest Plot: Effects of Plyometric Training vs Control Group on Strength Performance Outcomes. SMD: Standardized Mean Difference, CI: Confidence Interval, df: Degrees of Freedom, *p*: p-value



Study	Weight (%)	SMD	SE	95% CI
Harries et al., 2017	4.80	-0.214	0.453	-1.175 to 0.746
Harries et al., 2017	4.79	0.260	0.454	-0.702 to 1.222
Santos et al., 2012	4.54	1.753	0.466	0.788 to 2.717
Santos et al., 2012	4.26	1.942	0.481	0.947 to 2.937
Santos et al., 2012	4.53	1.760	0.467	0.794 to 2.725
Santos et al., 2012	4.64	1.683	0.461	0.729 to 2.637
Santos et al., 2012	5.65	0.962	0.418	0.0979 to 1.825
Channell et al., 2008	3.65	-1.013	0.520	-2.128 to 0.102
Flanagan et al., 2002	4.87	1.452	0.450	0.526 to 2.377
McKinlay et al., 2018	9.23	-0.198	0.327	-0.862 to 0.466
McKinlay et al., 2018	9.12	-0.364	0.329	-1.032 to 0.304
Moraes et al., 2013	6.17	0.0127	0.400	-0.816 to 0.842
Moraes et al., 2013	6.12	-0.245	0.401	-1.077 to 0.588
Lloyd et al., 2016	5.37	0.0789	0.428	-0.821 to 0.979
Lloyd et al., 2016	5.32	0.283	0.431	-0.622 to 1.187
Negra et al., 2016	4.19	1.839	0.485	0.830 to 2.848
Negra et al., 2016	3.20	2.595	0.555	1.440 to 3.749
Negra et al., 2016	5.06	1.228	0.441	0.310 to 2.145
Negra et al., 2016	4.50	1.622	0.468	0.649 to 2.595
Total (fixed effects)	100.00	0.659	0.0993	0.464 to 0.854
t=6.638; p<0.001				

Test for heterogeneity: Q, 92.3907; DF, 18; p<0.0001; I^2=80.52%; 95% CI for I^2= 70.42 to 87.17

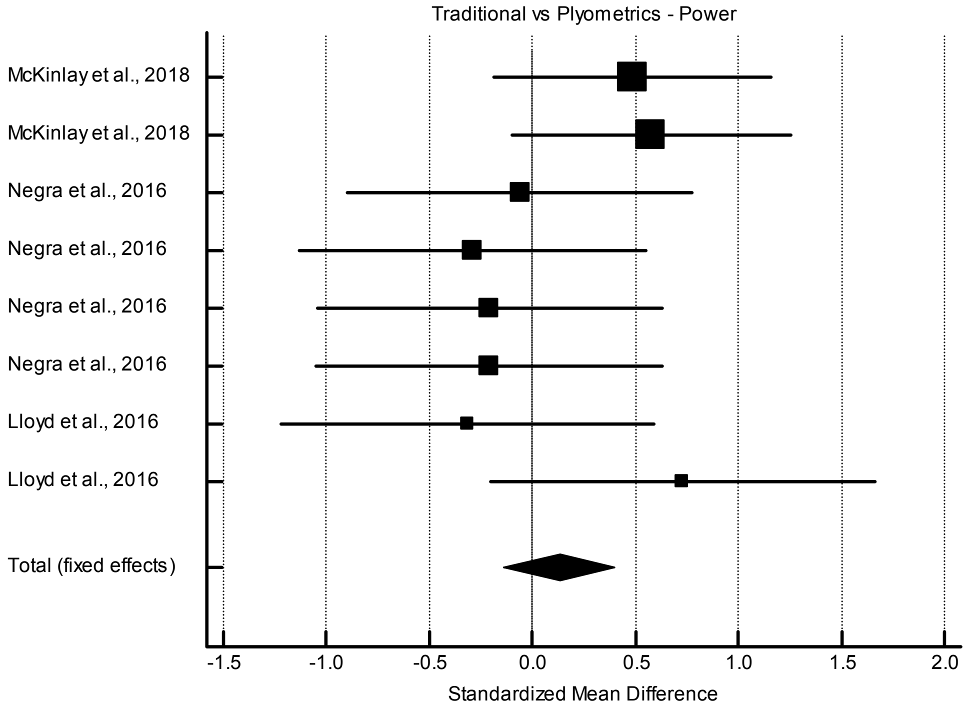
Figure 7. Forest Plot: Effects of Traditional Periodization vs Control Group on Power Performance Outcomes. SMD: Standardized Mean Difference, CI: Confidence Interval, df: Degrees of Freedom, *p*: p-value



Study	Weight (%)	SMD	SE	95% CI
Bartolomei et al., 2014	13.07	0.147	0.400	-0.684 to 0.977
Bartolomei et al., 2014	12.79	0.435	0.405	-0.404 to 1.274
Harries et al., 2017	9.20	-0.921	0.477	-1.932 to 0.0902
Harries et al., 2017	7.42	-1.679	0.531	-2.805 to -0.552
Bartolomei et al., 2015	9.85	0.000	0.461	-0.983 to 0.983
Bartolomei et al., 2015	9.54	0.484	0.469	-0.514 to 1.483
Moraes et al., 2013	15.51	0.141	0.367	-0.614 to 0.896
Moraes et al., 2013	15.25	0.388	0.371	-0.374 to 1.149
Baker et al., 1994	7.39	-0.238	0.532	-1.409 to 0.934
Total (fixed effects)	100.00	-0.0249	0.145	-0.310 to 0.261
t=-0.172; p=0.864				

Test for heterogeneity: Q=17.4792; DF = 8; p<0.0255; I^2=54.23%; 95% CI for I^2= 3.00 to 78.40

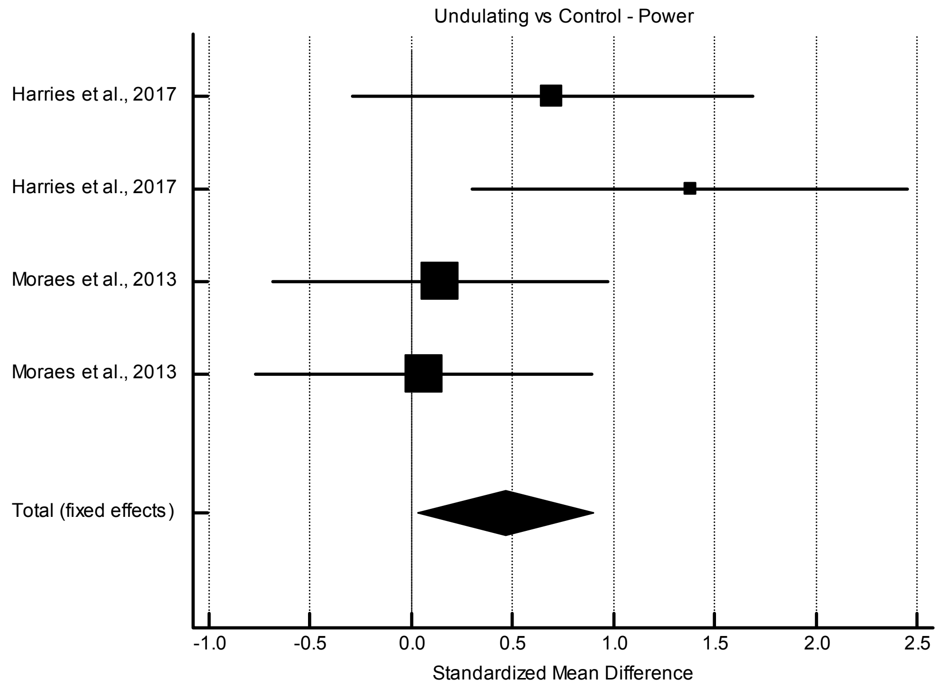
Figure 8. Forest Plot: Effects of Traditional Periodization vs Undulating Periodization on Power Performance Outcomes. SMD: Standardized Mean Difference, CI: Confidence Interval, df: Degrees of Freedom, *p*: p-value



Study	Weight (%)	SMD	SE	95% CI
McKinlay et al., 2018	17.17	0.488	0.331	-0.185 to 1.160
McKinlay et al., 2018	16.97	0.575	0.333	-0.102 to 1.251
Negra et al., 2016	11.61	-0.0599	0.402	-0.897 to 0.777
Negra et al., 2016	11.49	-0.287	0.405	-1.128 to 0.554
Negra et al., 2016	11.55	-0.207	0.403	-1.046 to 0.632
Negra et al., 2016	11.55	-0.212	0.404	-1.051 to 0.627
Lloyd et al., 2016	10.11	-0.317	0.431	-1.223 to 0.588
Lloyd et al., 2016	9.56	0.729	0.443	-0.203 to 1.660
Total (fixed effects)	100.00	0.130	0.137	-0.140 to 0.401
t=0.951; p=0.342				

Test for heterogeneity: Q=8.5536; DF = 7; p<0.2863; I^2=18.16%; 95% CI for I^2= 0.00 to 60.97

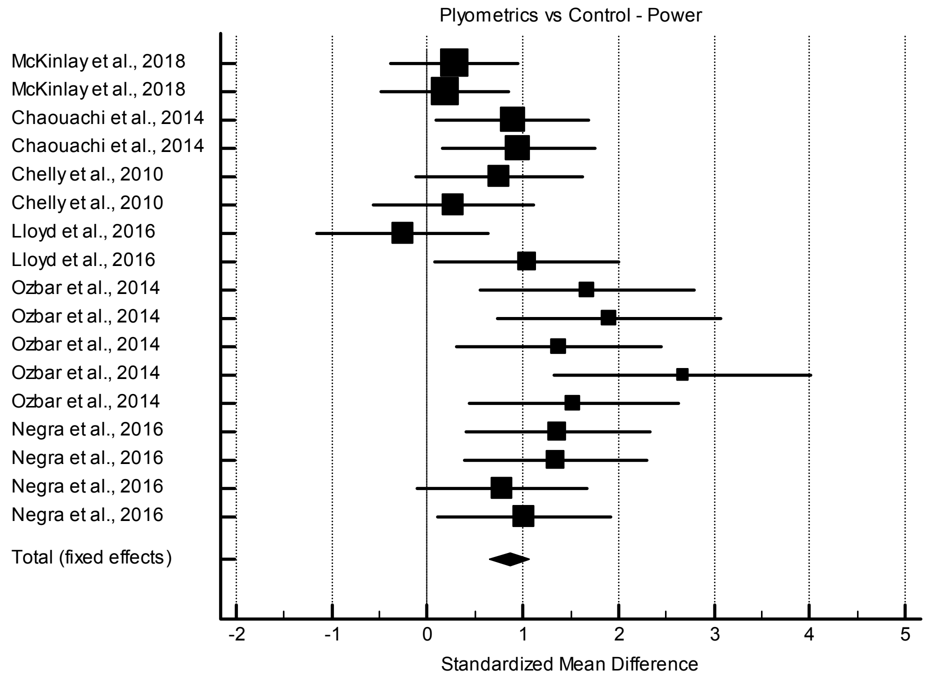
Figure 9. Forest Plot: Effects of Traditional Periodization vs Plyometric Training on Power Performance Outcomes. SMD: Standardized Mean Difference, CI: Confidence Interval, df: Degrees of Freedom, *p*: p-value



Study	Weight (%)	SMD	SE	95% CI
Harries et al., 2017	21.90	0.699	0.466	-0.290 to 1.688
Harries et al., 2017	18.56	1.378	0.507	0.304 to 2.452
Moraes et al., 2013	29.74	0.142	0.400	-0.688 to 0.972
Moraes et al., 2013	29.80	0.0607	0.400	-0.768 to 0.890
Total (fixed effects)	100.00	0.469	0.218	0.0349 to 0.903
t=2.149; p=0.035				

Test for heterogeneity: Q=5.1680; DF=3; p=0.1599; I^2=41.95%; 95% CI for I^2= 0.00 to 80.46

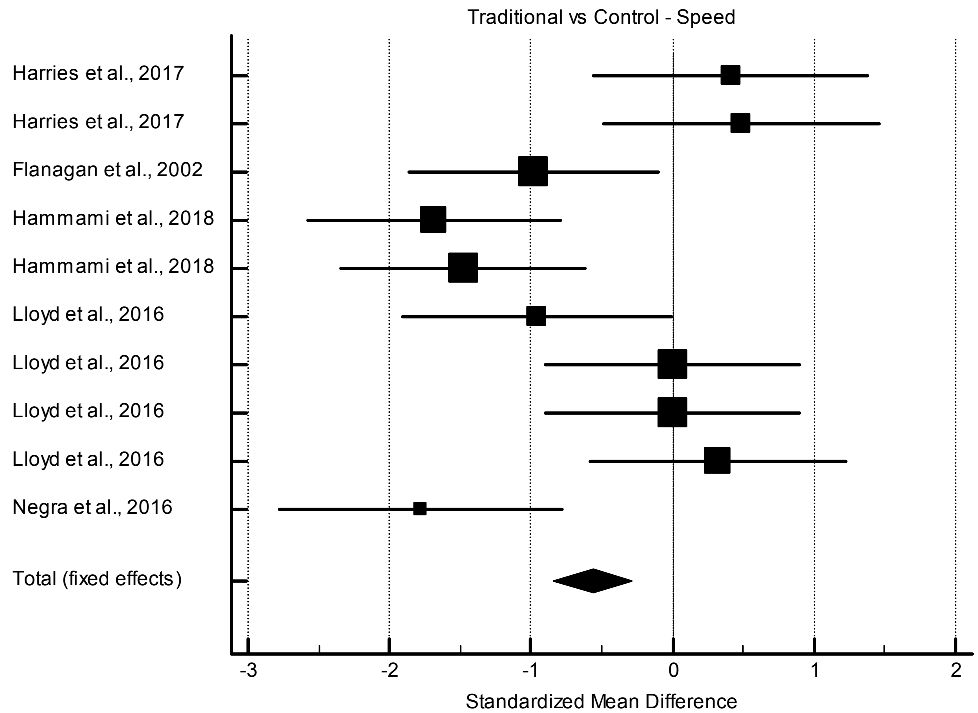
Figure 10. Forest Plot: Effects of Undulating Periodization vs Control Group on Power Performance Outcomes. SMD: Standardized Mean Difference, CI: Confidence Interval, df: Degrees of Freedom, *p*: p-value



Study	Weight (%)	SMD	SE	95% CI
McKinlay et al., 2018	10.20	0.282	0.328	-0.384 to 0.948
McKinlay et al., 2018	10.26	0.185	0.327	-0.479 to 0.849
Chaouachi et al., 2014	7.36	0.891	0.386	0.0984 to 1.684
Chaouachi et al., 2014	7.25	0.954	0.388	0.156 to 1.753
Chelly et al., 2010	6.29	0.749	0.417	-0.118 to 1.617
Chelly et al., 2010	6.70	0.276	0.404	-0.565 to 1.117
Lloyd et al., 2016	5.91	-0.260	0.430	-1.164 to 0.643
Lloyd et al., 2016	5.20	1.044	0.459	0.0794 to 2.008
Ozbar et al., 2014	3.93	1.666	0.528	0.547 to 2.785
Ozbar et al., 2014	3.62	1.905	0.550	0.739 to 3.070
Ozbar et al., 2014	4.31	1.372	0.504	0.304 to 2.440
Ozbar et al., 2014	2.73	2.677	0.633	1.335 to 4.018
Ozbar et al., 2014	4.11	1.531	0.516	0.436 to 2.626
Negra et al., 2016	5.19	1.367	0.459	0.410 to 2.325
Negra et al., 2016	5.22	1.351	0.458	0.396 to 2.307
Negra et al., 2016	6.00	0.787	0.427	-0.103 to 1.678
Negra et al., 2016	5.71	1.013	0.438	0.100 to 1.926
Toa (fixed effects)	100.00	0.863	0.105	0.658 to 1.069
t= 8.252; p<0.001				

Test for heterogeneity: Q=35.9783; DF=16; p=0.0029; I^2=55.53%; 95% CI for I^2= 23.32 to 74.21

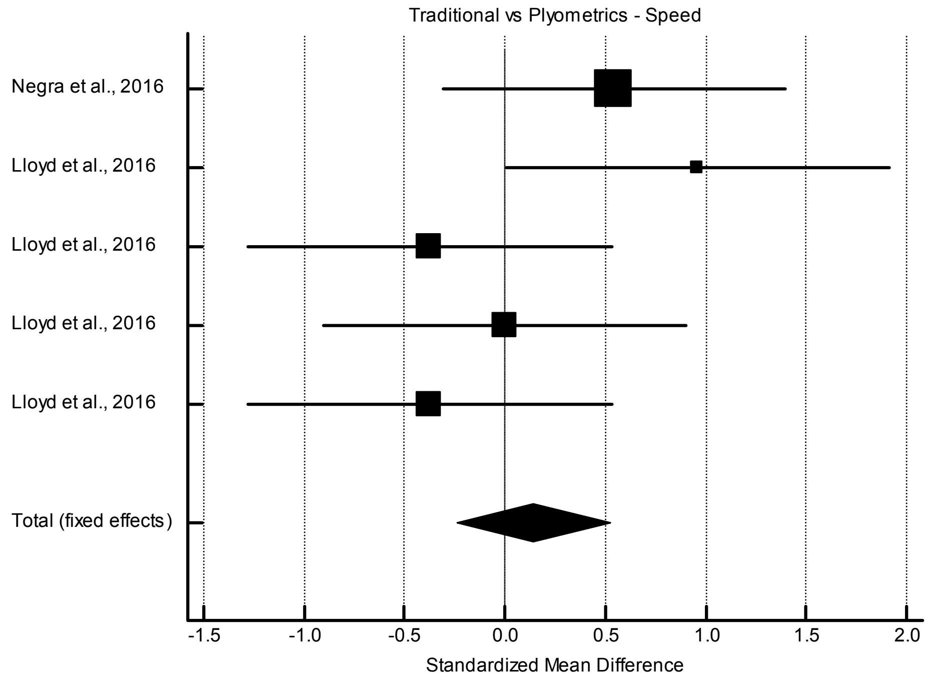
Figure 11. Forest Plot: Effects of Plyometric Training vs Control Group on Power Performance Outcomes. SMD: Standardized Mean Difference, CI: Confidence Interval, df: Degrees of Freedom, *p*: p-value



Study	Weight (%)	SMD	SE	95% CI
Harries et al., 2017	9.30	0.411	0.457	-0.557 to 1.380
Harries et al., 2017	9.22	0.489	0.459	-0.484 to 1.462
Flanagan et al., 2002	10.67	-0.980	0.427	-1.857 to -0.103
Hammami et al., 2018	10.33	-1.683	0.434	-2.574 to -0.791
Hammami et al., 2018	11.01	-1.476	0.420	-2.339 to -0.612
Lloyd et al., 2016	9.41	-0.958	0.454	-1.912 to -0.00330
Lloyd et al., 2016	10.59	0.000	0.428	-0.900 to 0.900
Lloyd et al., 2016	10.59	0.000	0.428	-0.900 to 0.900
Lloyd et al., 2016	10.44	0.319	0.431	-0.587 to 1.225
Negra et al., 2016	8.43	-1.774	0.480	-2.772 to -0.776
Total (fixed effects) t=-4.047; p<0.001	100.00	-0.564	0.139	-0.839 to -0.289

Test for heterogeneity: Q, 36.9119; DF, 9; p<0.0001; I^2=75.62%; 95% CI for I^2= 54.72 to 86.87

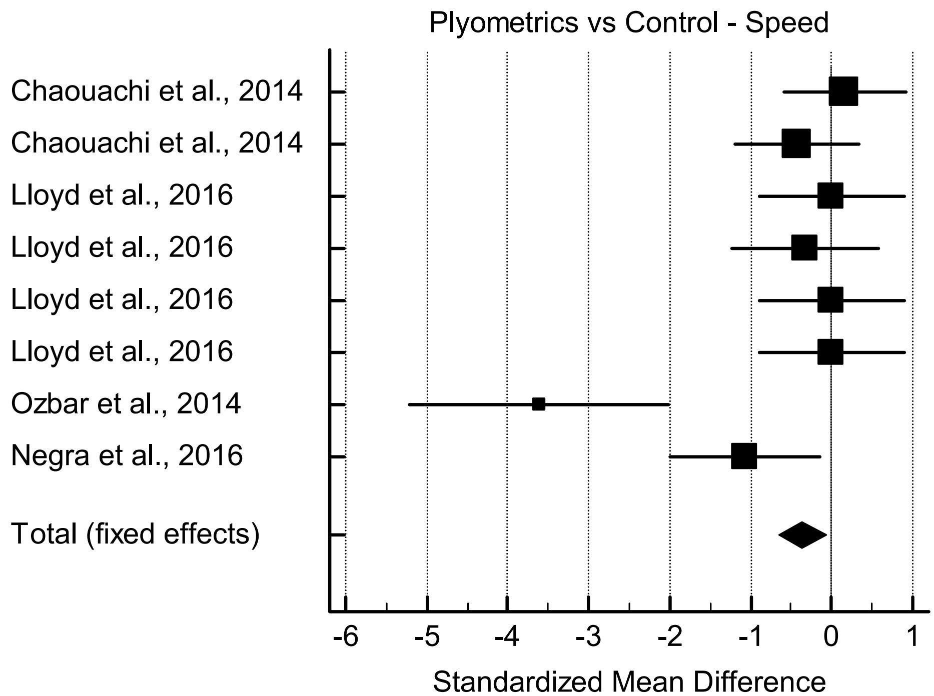
Figure 12. Forest Plot: Effects of Traditional Periodization vs Control Group on Speed Performance Outcomes. SMD: Standardized Mean Difference, CI: Confidence Interval, df: Degrees of Freedom, *p*: p-value



Study	Weight (%)	SMD	SE	95% CI
Negra et al., 2016	22.06	0.543	0.410	-0.310 to 1.396
Lloyd et al., 2016	17.99	0.958	0.454	0.00330 to 1.912
Lloyd et al., 2016	19.86	-0.376	0.432	-1.284 to 0.533
Lloyd et al., 2016	20.24	0.000	0.428	-0.900 to 0.900
Lloyd et al., 2016	19.86	-0.376	0.432	-1.284 to 0.533
Total (fixed effects)	100.00	0.143	0.193	-0.239 to 0.525
t=0.741; p=0.460				

Test for heterogeneity: Q=7.1539; DF = 4; p<0.1280; I^2=66.76; 95% CI for I^2= 0.00 to 79.48

Figure 13. Forest Plot: Effects of Traditional Periodization vs Plyometric Training on Speed Performance Outcomes. SMD: Standardized Mean Difference, CI: Confidence Interval, df: Degrees of Freedom, *p*: p-value



Study	Weight (%)	SMD	SE	95% CI
Chaouachi et al., 2014	17.09	0.161	0.368	-0.594 to 0.917
Chaouachi et al., 2014	16.76	-0.420	0.371	-1.184 to 0.343
Lloyd et al., 2016	12.59	0.000	0.428	-0.900 to 0.900
Lloyd et al., 2016	12.42	-0.319	0.431	-1.225 to 0.587
Lloyd et al., 2016	12.59	0.000	0.428	-0.900 to 0.900
Lloyd et al., 2016	12.59	0.000	0.428	-0.900 to 0.900
Ozbar et al., 2014	4.09	-3.614	0.751	-5.206 to -2.021
Negra et al., 2016	11.88	-1.074	0.441	-1.993 to -0.154
Total (fixed effects)	100.00	-0.358	0.152	-0.658 to -0.0580
t=-2.355; p=0.020				

Test for heterogeneity: Q=25.5457; DF=7; p=0.0006; I^2=72.60%; 95% CI for I^2= 43.91 to 86.61

Figure 14. Forest Plot: Effects of Plyometric Training vs Control Group on Speed Performance Outcomes. SMD: Standardized Mean Difference, CI: Confidence Interval, df: Degrees of Freedom, *p*: p-value

REFERENCES

1. Comstock, R. Dawn; Currie, Dustin; Pierpoint L. 2016-17 HIGH SCHOOL ATHLETICS PARTICIPATION SURVEY Conducted By THE NATIONAL FEDERATION OF STATE HIGH SCHOOL ASSOCIATIONS Based on Competition at the High School Level in the 2016-17 School Year BOYS GIRLS COMBINED Sport (Number of states reporting Number. http://www.nfhs.org/ParticipationStatistics/PDF/2016-17_Participation_Survey_Results.pdf. Accessed November 20, 2017.

2. Committee on Sports Medicine and Fitness. Intensive Training and Sports Specialization in Youth Athletes. *Pediatrics*. 2000;106(6):154-157.

3. Committee on Sports Medicine and Fitness. Strength Training by Children and Adolescents. *Pediatrics*. 2000;106(6):154-157.

4. Foschini D, Araújo RC, Bacurau RFP, et al. Treatment of Obese Adolescents: The Influence of Periodization Models and ACE Genotype. *Obesity*. 2010;18(4):766-772. doi:10.1038/oby.2009.247

5. Myers AM, Beam NW, Fakhoury JD. Resistance training for children and adolescents. *Transl Pediatr*. 2017;6(3):137-143. doi:10.21037/tp.2017.04.01

6. Brenner JS. Sports Specialization and Intensive Training in Young Athletes. *Pediatrics*. 2016;138(3):e20162148-e20162148. doi:10.1542/peds.2016-2148

7. Schwager T. Strength Training for Kids. *Am Fit*. 2010;28(5):20-22. http://ezproxy.library.uvic.ca/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=sph&AN=53305268&site=ehost-live&scope=site.

8. Apel JM, Lacey RM, Kell RT. A Comparison of Traditional and Weekly Undulating Periodized Strength Training Programs With Total Volume and Intensity Equated. *J Strength Cond Res*. 2011;25(3):694-703. doi:10.1519/JSC.0b013e3181c69ef6

9. Harries SK, Lubans DR, Buxton A, MacDougall THJ, Callister R. Effects of 12-weeks resistance training on sprint and jump performance in competitive adolescent rugby union players. *J Strength Cond Res*. 2017. doi:10.1519/JSC.0000000000002119

10. Harries SK, Lubans DR, Callister R. Systematic Review and Meta-analysis of Linear and Undulating Periodized Resistance Training Programs on Muscular Strength. *J Strength Cond Res*. 2015;29(4):1113-1125. doi:10.1519/JSC.0000000000000712

11. Fleck SJ. Non-Linear Periodization for General Fitness & Athletes. *J Hum Kinet Spec Issue*. 2011:41-45. doi:10.2478/v10078-011-0057-2

12. Miranda F, Simão R, Rhea M, et al. Effects of Linear vs. Daily Undulatory Periodized Resistance Training on Maximal and Submaximal Strength Gains. *J Strength Cond Res*. 2011;25(7):1824-1830. doi:10.1519/JSC.0b013e3181e7ff75

13. Grgic J, Mikulic P, Podnar H, Pedisic Z. Effects of linear and daily undulating periodized resistance training programs on measures of muscle hypertrophy: a systematic review and meta-analysis. *PeerJ*. 2017;5:e3695. doi:10.7717/peerj.3695

14. Bedoya AA, Miltenberger MR, Lopez RM. Plyometric Training Effects on Athletic Performance in Youth Soccer Athletes. *J Strength Cond Res*. 2015;29(8):2351-2360. doi:10.1519/JSC.0000000000000877

15. Asadi A, Arazi H, Ramirez-Campillo R, Moran J, Izquierdo M. Influence of Maturation Stage on Agility Performance Gains After Plyometric Training: A Systematic Review and Meta-analysis. *J strength Cond Res*. 2017;31(9):2609-2617. doi:10.1519/JSC.0000000000001994

16. Slimani M, Paravlić A, Bragazzi NL. Data concerning the effect of plyometric training on jump performance in soccer players: A meta-analysis. *Data Br*. 2017;15:324-334. doi:10.1016/j.dib.2017.09.054

17. Rhea MR, Alvar BA, Burkett LN, Ball SD. A meta-analysis to determine the dose response for strength development. *Med Sci Sports Exerc*. 2003;35(3):456-464. doi:10.1249/01.MSS.0000053727.63505.D4

18. Lakens D. Calculating and reporting effect sizes to facilitate cumulative science: a practical primer for t-tests and ANOVAs. *Front Psychol*. 2013;4:863. doi:10.3389/fpsyg.2013.00863

19. Peitz M, Behringer M, Granacher U. A systematic review on the effects of resistance and plyometric training on physical fitness in youth- What do comparative studies tell us? Padulo J, ed. *PLoS One*. 2018;13(10):e0205525. doi:10.1371/journal.pone.0205525

20. Moraes E, Fleck SJ, Ricardo Dias M, Simão R, Dias MR, Simão R. Effects on strength, power, and flexibility in adolescents of nonperiodized vs. daily nonlinear periodized weight training. *J Strength Cond Res*. 2013;27(12):3310-3321. doi:10.1519/JSC.0b013e31828de8c3

21. Faigenbaum AD, Kraemer WJ, Blimkie CJR, et al. Youth Resistance Training: Updated Position Statement Paper From the National Strength and Conditioning Association. *J Strength Cond Res*. 2009. doi:10.1519/JSC.0b013e31819df407

22. Bartolomei S, Hoffman JR, Merni F, Stout JR. A Comparison of Traditional and Block Periodized Strength Training Programs in Trained Athletes. *J Strength Cond Res*. 2014;28(4):990-997. doi:10.1519/JSC.0000000000000366

23. Behringer M, Neuerburg S, Matthews M, Mester J. Effects of two different resistance-training programs on mean tennis-serve velocity in adolescents. *Pediatr Exerc Sci*. 2013;25(3):370-384. http://www.ncbi.nlm.nih.gov/pubmed/23986524. Accessed January 26, 2019.

24. Silva JM. An analysis of the training stress syndrome in competitive athletics. *J Appl Sport Psychol*. 1990;2(1):5-20. doi:10.1080/10413209008406417

25. Moran J, Sandercock GRH, Ramírez-Campillo R, Meylan C, Collison J, Parry DA. Age-related variation in male youth athletes' countermovement jump following plyometric training. *J Strength Cond Res*. April 2016:1. doi:10.1519/JSC.0000000000001444

26. Lloyd RS, Oliver JL, Hughes MG, Williams CA. The Effects of 4-Weeks of Plyometric Training on Reactive Strength Index and Leg Stiffness in Male Youths. *J Strength Cond Res*. 2012;26(10):2812-2819. doi:10.1519/JSC.0b013e318242d2ec

27. Cunanan AJ, DeWeese BH, Wagle JP, et al. The General Adaptation Syndrome: A Foundation for the Concept of Periodization. *Sport Med*. 2018;48(4):787-797. doi:10.1007/s40279-017-0855-3

28. Lloyd RS, Radnor JM, De Ste Croix MBA, Cronin JB, Oliver JL. Changes in Sprint and Jump Performances After Traditional, Plyometric, and Combined Resistance Training in Male Youth Pre- and Post-Peak Height Velocity. *J Strength Cond Res*. 2016;30(5):1239-1247. doi:10.1519/JSC.0000000000001216

29. Negra Y, Chaabene H, Stöggl T, Hammami M, Chelly MS, Hachana Y. Effectiveness and time-course adaptation of resistance training vs. plyometric training in prepubertal soccer players. *J Sport Heal Sci*. 2016. doi:10.1016/j.jshs.2016.07.008

30. Jolles DD, Crone EA. Training the developing brain: a neurocognitive perspective. *Front Hum Neurosci*. 2012;6:76. doi:10.3389/fnhum.2012.00076

31. Hawley JA. Specificity of training adaptation: time for a rethink? *J Physiol*. 2008;586(1):1-2. doi:10.1113/jphysiol.2007.147397

32. Harries SK, Lubans DR, Callister R. Resistance training to improve power and sports performance in adolescent athletes: A systematic review and meta-analysis. *J Sci Med Sport*. 2012;15(6):532-540. doi:10.1016/J.JSAMS.2012.02.005

33. Kraemer WJ, Torine JC, Dudley J, Martin GJ. Nonlinear Periodization. *Strength Cond J*. 2015;37(6):17-36. doi:10.1519/SSC.0000000000000179

34. Sale DG. Neural adaptation to resistance training. *Med Sci Sports Exerc*. 1988;20(5 Suppl):S135-45. http://www.ncbi.nlm.nih.gov/pubmed/3057313. Accessed March 15, 2019.

35. Grgic J, Mikulic P, Podnar H, Pedisic Z. Effects of linear and daily undulating periodized resistance training programs on measures of muscle hypertrophy: a systematic review and meta-analysis. *PeerJ*. 2017;5:e3695. doi:10.7717/peerj.3695