Effects of combined resistance training and weightlifting on injury risk factors and resistance training skill of adolescent males

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ABSTRACT

The purpose of this study was to investigate the effects of resistance training with or without weightlifting on risk factors for injury and resistance training skill in circa-peak height velocity boys. Sixty-seven boys (age 12-14 years) from a local secondary school were divided into three groups: combined resistance training (CRT), combined resistance training with weightlifting movements (CRT&WL), or a control group (CON). Experimental groups completed twice-weekly training programs over the course of an academic year. The tuck jump assessment, asymmetry measures for single-leg horizontal jump, isometric mid-thigh pull, and the Star Excursion Balance Test, and resistance training skill were measured pre-, mid-, and post-intervention. Only the CRT group significantly improved tuck jump assessment score pre- to post-test (p = 0.006, -20.4%, d = -0.39) but there were no clear effects on asymmetry measures for any group. Both groups significantly improved resistance training skill from pre- to post-test (CRT&WL: p = 0.002, 17.6%, d = 1.00; CRT: p = 0.026, 9.2%, d = 0.53). This study suggests that a school-based CRT program may provide significant improvements in jump landing kinematics, whereas the inclusion of weightlifting movements may provide greater improvements in resistance training skill.

KEY WORDS: strength training, plyometrics, resistance training skills battery, tuck jump assessment, interlimb asymmetry

WORD COUNT: 180

INTRODUCTION

Lower-extremity injury incidence is heightened due to reduced neuromuscular control during peak height velocity (PHV) (50), a period of accelerated growth that on average occurs between ages 13.5-14.5 in males (1, 18). Previous research has identified several factors such as jump landing kinematics (40, 41), interlimb asymmetry (2, 6, 7), and movement skill (24) that contribute to injury risk or reduced performance as result of this temporary loss in neuromuscular control. Much of the available research examining lower-extremity injury risk in adolescents has focused on knee kinematics during jump landing tasks (3, 4, 33). One cross-sectional study of pre-, circa-, and post-PHV male soccer players demonstrated that a circa-PHV group experienced greater relative force during the landing of a single-leg countermovement jump, although knee valgus declined with maturation (40). Furthermore, notable asymmetries of knee valgus during the tuck jump assessment were found in a cross-sectional study of and circa-PHV of 400 athletes from professional English soccer academies (39). The tuck jump assessment is a practitioner-friendly assessment used to identify high-risk landing mechanics that requires little equipment (31), which makes it ideal for school and team settings. However, only one study has examined the changes in tuck jump scores after a training intervention (20). Specifically, a 10-week injury prevention program that consisted of body weight exercises failed to improve tuck jump scores more than a control group performing regular soccer training, which suggests that a longer duration or greater training stimulus may be necessary to improve neuromuscular control. Since relatively short interventions using body weight exercises alone may not be sufficient to elicit improvements, further research investigating the effects of longer resistance training programs with greater external load on tuck jump assessment scores is warranted.

In addition to lower-extremity mechanics during jump-landing tasks, interlimb asymmetry of jump, strength, and balance tests may contribute to risk of injury (36) or reduced performance (2, 6, 7). For example, higher injury rates were associated with isokinetic strength asymmetry measures greater than 15% in collegiate athletes (21), though limited research has examined this threshold in young athletes. In terms of the impact of interlimb asymmetry on performance, Bishop et al. (6) found strong relationships between single-leg jump asymmetry and sprint performance (r = 0.79-0.87), as well as change of direction performance (r = 0.63-0.85) in elite U16 soccer players. Another study by Bailey et al. (2) found significant relationships between isometric midthigh pull interlimb asymmetry and bilateral jump height (r = -0.47 to -0.52). Finally, high school basketball players with an asymmetry greater than or equal to 4 cm for the anterior reach distance of the Star Excursion Balance Test (SEBT) were 2.5 times more likely to sustain a lower-extremity injury during the season (36). Several studies have demonstrated that targeted training can reduce asymmetries (44, 45), but these studies were conducted in a sporting environment, where a more targeted approach can be delivered by sport coaches. Thus, further investigation is needed to determine the effects of a school-based resistance training program on interlimb asymmetry of adolescent males. Since interlimb asymmetries are linked to injury and reduced performance (2, 36), practitioners should aim to reduce asymmetry values during adolescence when risk of injury is greater due to decreased neuromuscular function.

Numerous movement skill assessments have been shown to be reliable in youth populations (13, 14, 25, 32, 42). When practicing within a school setting, practitioners should aim to choose a movement assessment that can be efficiently implemented given the time constraints of school curriculum. The Resistance Training Skills Battery (RTSB) was designed as a measurement tool used to evaluate the efficacy of school-based resistance training programs on movement skill competency (25). Given the aims of the RTSB, it was designed with the constraints of a school setting in mind and therefore requires minimal equipment and can easily be conducted by educators and pediatric researchers. However, only two studies have examined changes in resistance training skill after an intervention (19, 47). These studies found significant improvements in resistance training skill of an adolescent aged training group compared to a control group after a 10-week (19) and 20-week intervention (46). These improvements were sustained up to 18 months following cessation of training (19, 26), which suggests students and athletes retain these skills once developed. Due to the heightened neural plasticity associated with childhood, resistance training skills should be taught as early as possible to aid in long-term athletic development (23).

Resistance training interventions have been lauded for their effectiveness in decreasing injury risk factors (51) and improving movement (22). Previous research suggests weightlifting exercises specifically may help reduce injury by improving the kinetics and kinematics associated with landing, cutting, and deceleration movements (30). Weightlifting training, which refers to the snatch, clean and jerk, and their derivatives, involves a rapid concentric action, followed by an eccentric action during the catch, or absorption phase following the second pull - a pattern similar to landing and cutting activities. Of note, Suchomel et al. (49) found that exercises without the catch phase of the lift produce greater load absorption demands than a hang clean (which includes a catch), which indicates that training with derivatives of the full weightlifting lifts can be a valuable method to improve load absorption and reduce risk factors for injury. However, research utilizing resistance training and weightlifting in youth populations has primarily measured performance based outcomes such as strength (8), speed (10), and jump performance (9), which neglects other potential benefits such as reducing injury risk or enhancing resistance training skill. Therefore, the purpose of this study was to investigate how combined resistance training with or without weightlifting movements affect injury risk factors, such as jump landing kinematics and interlimb asymmetry, as well as resistance training skill.

METHODS

Experimental Approach to the Problem

A cluster randomized controlled trial was used to determine the effects of either combined resistance training (CRT), a combined approach that included weightlifting movements (CRT&WL), or regular physical education curriculum (CON) on resistance training skill and risk factors for lower-extremity injuries in adolescent males after an academic year. Boys enrolled in an athlete development programme were matched by maturation and countermovement jump height, then divided into one of two training groups: CRT or CRT&WL training. Two age-matched physical education classes comprised the control group. The CRT group completed a combination of traditional resistance training and plyometric training, whereas the CRT&WL group also completed traditional resistance and plyometric training but replaced two or three of the strength-based exercises with weightlifting derivatives. Both training groups completed this training twice per week, in addition to regular physical education curriculum two to three times per week. When data collection weeks and school holidays were accounted for, each group completed 28 total weeks of training. The CON group completed their regular physical education curriculum two to three times per week. The physical education classes consisted of large and small ball sports to improve hitting, striking, catching, throwing, kicking, and kinaesthetic awareness, as well as an aquatics unit at a local pool. All participants completed the same battery of tests pre, mid- (14 training weeks) and post-training (28 training weeks), which included the RTSB, a tuck jump assessment, single leg horizontal jump, modified Star Excursion Balance Test (SEBT), and isometric mid-thigh pull.

Subjects

Sixty-seven year nine and ten boys (aged 12-14 years) from a secondary school in New Zealand volunteered to participate in this study. Forty boys from the school's athlete development program were matched by maturity offset (29) countermovement jump height and divided into either the CRT (n = 21) or CRT&WL group (n = 19), whereas the CON group (n = 27) was comprised of two age-matched physical education classes. Participant characteristics are presented in Table 1. All participants were engaged in a physical education curriculum but had less than nine months of any formal resistance training experience. Parental informed consent and participant assent were obtained before the study and ethical approval was granted by the Institutional Research Ethics Committee.

Table 1 near here

Procedures

Testing was completed during standard physical education classes on two non-consecutive days. The first testing session included collection of anthropometric measures, the isometric mid-thigh pull (IMTP) and the single-leg horizontal jump, whereas the second session included the RTSB, the tuck jump assessment and the modified SEBT. Participants completed a standardized dynamic warm-up that lasted approximately eight minutes and included body weight squats, lunges, and push-ups, as well as three submaximal sprints and jumps at 50, 70, and 90% effort. The athletic development and physical education classes were divided into even groups and performed the tests in a randomized order on the first testing session, but then performed the tests in the same order on subsequent testing sessions. This approach was used due to the number of participants and the time constraints of the school curriculum.

Anthropometrics

Standing height was measured to the nearest 0.1 cm using a stadiometer (Model: WSHRP; Wedderburn, New Zealand). Seated height was measured to the nearest 0.1 cm using a meter stick taped to a wall above a 40 cm wooden box. Body mass was measured to the nearest 0.1 kg using a digital scale (Model: TI390150K; Tanita, New Zealand). Maturity offset was determined using the following regression analysis based on age, body mass, standing height, and seated height (29): Maturity offset = -(9.236 + 0.0002708 * leg length and sitting height interaction)-(0.001663·age and leg length interaction) + (0.007216·Age and sitting height interaction) + (0.02292 * weight by height ratio). This equation, which has a standard error of 0.57 years in males, is a non-invasive method to predict maturity status (29).

Resistance Training Skills Battery

Participants were screened using a modified version of the RTSB, which provides an assessment of basic resistance training skill competency (25). This screen includes six body weight movements: body weight squat with a dowel rod, lunge, suspended row, standing overhead press, front support with chest touches and push-up, which were performed in a randomized order. Participants performed four repetitions of each movement and were filmed from the frontal and sagittal plane with an iPad (3^{rd} and 4^{th} generation, Apple Inc., USA) on a tripod one m high and three m from the participant. Each movement was rated retrospectively by an experienced rater according to the criteria established by Lubans et al. (25). The best repetition of each movement was scored according to four (push-up and suspended row) or five (body weight squat, lunge, standing overhead press and front support with chest touches) movement criteria. The resistance training skills quotient (RTSQ) was determined by adding the score for each skill together, which results in a score of 0-56. Although the traditional RTSB requires participants to perform two sets of four repetitions for each movement, only one set of each exercise was performed due to time restrictions of the school curriculum, so the score for each exercise was doubled for a total of eight or 10 for movements scored out of four or five criteria, respectively. A pilot study undertaken with a small sub-sample of 10 participants rated and re-rated 7 days later demonstrated acceptable relative reliability for individual movements (intraclass correlation coefficient [ICC] = 0.71-0.95) and RTSQ (ICC = 0.97), which is comparable to the original protocol from Lubans et al. (25) (ICC = 0.67-0.88) and an adapted version from Bebich-Philip et al. (5) (ICC = 0.87-0.97).

Tuck jump assessment

Participants stood with their feet on two parallel pieces of tape 35 cm apart, connected by a horizontal portion, forming an H-shape (48). Participants were instructed to jump as high as possible, raise their knees as high as possible and begin the next jump immediately after landing. A research assistant demonstrated proper technique prior to participants completing the assessment. Each participant performed the tuck jumps for 10 seconds, or until technique declined and they were unable to complete another repetition. Digital cameras placed in the frontal and sagittal planes were used to record the assessment for retrospective rating according to criteria from Myer et al. (31). The tuck jump assessment has shown strong reliability (ICC = 0.88) in young male athletes (38).

Single leg horizontal jump

The horizontal jump was measured using a tape measure affixed to a wooden gymnasium floor. Participants were instructed to place hands on hips, stand on one leg with their toe behind a line, then jump as far as possible and land on two legs. Distance was recorded from the heel of the rearmost foot upon landing to the nearest centimetre. Trials were not valid if the participant's hands came off the hips or they moved one of their feet upon landing. Each participant performed two jumps with each leg and were given approximately one-minute rest between jumps. The best jump distance was used for asymmetry analysis. Horizontal jump distance has shown high reliability in adolescents (ICC = 0.63-0.96, CV = 3.8-9.4%) (28).

Isometric mid-thigh pull

Participants performed the isometric mid-thigh pull with a fixed barbell standing on two portable force platforms sampling at 100 Hz (Pasco, Roseville, CA). The force plates were placed on dense, incompressible rubber mats that were added or taken away to adjust the height of the bar in one cm increments for each participant. A self-selected posture which replicated the second pull of a clean was used, as previous research has demonstrated high reliability with this technique (12). Each participant had an upright torso with hands placed outside their legs, the bar positioned at mid-thigh, and knee and hip angles of approximately 125-145° and 140-150°, respectively (11). Participants were instructed to push their feet into the ground as hard and as fast as possible. A countdown of *"Three, two, one, pull!"* was given, at which point each participant pulled maximally for approximately three seconds with verbal encouragement provided. Each participant completed two trials with approximately one-minute rest. Trials were discounted and repeated if there was a noticeable countermovement, or if the participant lost grip. The best trial on each leg was used for asymmetry analysis. Peak force reflected the maximum force (N) generated during each trial for each leg and was analysed using custom Labview software (National Instruments). This protocol has shown high between-session (ICC = 0.96, CV = 4.61%) reliability in adolescent males (15).

Figure 1 near here

Star Excursion Balance Test

The reach distance of the anterior, posteromedial, and posterolateral direction of the SEBT were measured using three tape measures taped to the floor. A goniometer was used to fix the posterolateral and posteromedial tape measures at a 135° angle. Participants were instructed to place their big toe at the intersection of the three tape measures, place their hands on their hips, and reach as far as possible along the tape in each direction. Each participant performed two successful trials in each direction in a randomized order. A trial was discounted and repeated if one of the following occurred: the participant's hands were removed from the hips, their stance foot or heel was moved, they did not return to the starting position in a controlled manner, or they heavily placed their reach foot on the ground to retain balance. The intra-rater reliability of the SEBT has been high (ICC = 0.84-0.99) in previous studies assessing secondary school students (36, 41).

Training Program

Guidelines for the training programs is shown in Table 2 and has been described elsewhere in more detail (35). Briefly, both training groups completed 28 weeks of training over the course of an academic year. Both groups performed the same speed, agility, and plyometric exercises outside on a turf field or inside a gymnasium. However, the resistance training exercises within the weight room varied depending on group. The CRT group performed traditional resistance training exercises, whereas the CRT&WL group replaced two or three of the main exercises with weightlifting exercises and derivatives that were similar in range of motion and muscles used. For example, when the CRT group performed a deadlift, the CRT&WL group performed a clean pull. Volume was matched by sets and reps, but not total volume load since the movements were loaded to different degrees. Movements and load were assigned and progressed based on technical competency, similar to suggested approaches for athletes with varying skill levels (27, 34). All weight room training was supervised, and feedback was given by a certified strength and conditioning specialist (CSCS®) with a USA Weightlifting certification. There were no injuries that caused a loss in training time as a result of the training program.

Table 2 near here

Statistical Analysis

Descriptive statistics (mean ± SD) were calculated for all variables. Kolmogorov-Smirnov tests revealed that the RTSQ were the only normally distributed data. Therefore, for the RTSQ, the Maulchy's Test was used to assess sphericity and if violated, the Greenhouse-Geisser adjustment was applied. A 3 × 3 repeated-measures analysis of variance (ANOVA) was used to determine between-group differences at pre-, mid-, and post-test, as well as within-group differences between time points. Bonferroni post hoc tests were used to determine the location of any differences. For the non-normally distributed data (individual RTSB skills and asymmetry measures), Kruskal-Wallis tests were used to determine between-group differences at pre-, mid-, and post-test with Mann-Whitney U post hoc tests used to determine the location of any significant differences. Friedman tests were used to determine within-group effects of time, with a Wilcoxon signed rank test used to determine significant changes between time points. Within-group effect sizes for the RTSQ were calculated in Microsoft Excel (Version 16) and were interpreted according to Cohen's *d* statistic. Interlimb asymmetry for the single-leg horizontal jump, IMTP, and SEBT was calculated using the following equation: [(highest performing limb – lowest performing limb) / lowest performing limb] × 100 (41). Inter-trial reliability was calculated using pairwise comparisons on log-transformed data to reduce the effects of any non-uniformity of error (17). The typical error was expressed as a coefficient of variation (CV) to determine absolute reliability and the intraclass correlation coefficient (ICC) was used to determine relative reliability. Average participant percentage change between time points was also calculated for each group using Excel. The descriptive statistics, repeated measures ANOVA, and non-parametric tests were all calculated using SPSS version 25 (SPSS Inc., Chicago, IL, USA). Statistical significance was set at an alpha level of $p \leq 0.05$ for all tests.

Results

All variables showed acceptable absolute (CV ≤ 15%) and relative (ICC ≥ 0.70) intrasession reliability, respectively: IMTP (CV = 10.0-11.1%, ICC = 0.89-0.91); single-leg horizontal jump (CV = 5.2-5.5%, ICC = 0.89-0.90); SEBT (CV = 4.3-5.7%, ICC = 0.72-0.81). For the tuck jump assessment, there was no difference between groups at baseline ($p = 0.96$). The CRT and CRT&WL groups scored significantly better than the CON group at the mid-test ($p = 0.01$ and 0.04, respectively), but only the CRT group scored significantly better than the CON group at post-test ($p = 0.03$). The CRT group significantly decreased their tuck jump score from pre- to mid- ($p = 0.04$, -8.9%, $d = -0.68$) and pre- to post-test ($p = 0.01$, -20.4%, $d = -0.39$), as shown in Figure 2. The CRT&WL and CON group did not significantly improve between any two time points.

The asymmetry measures and within-group changes are displayed in Table 2. There were no between-group differences for any of the asymmetry measures at any time point (all $p \geq 0.10$). Asymmetry for the IMTP significantly decreased from mid- to post-test for the CRT&WL group ($p = 0.02$, -8.65%, $d = -0.76$). Anterior reach asymmetry significantly decreased from mid- to post-test for the CON group ($p = 0.03$, -3.00%, $d = -0.54$). The CRT group's posterolateral reach asymmetry significantly decreased from pre- to mid-test ($p = 0.01$, -2.70%,

d = -0.92), whereas the CON group significantly decreased from pre- to mid- (p = 0.002, -2.77%, d = -1.00) and pre- to post-test (p = 0.002, -2.23%, d = -0.81). There were no within-group changes for single-leg horizontal jump or posteromedial reach asymmetry (all $p > 0.05$).

Table 3 near here

The repeated measures ANOVA showed there were no significant group × time interactions for the RTSQ (p = 0.81), but there was a significant main effect for time ($p < 0.001$). Post hoc analysis revealed that the CRT group scored significantly higher than the CRT&WL group at baseline (p = 0.05) and significantly higher than the CON group at each time point (pre: p = 0.004, mid: p = 0.002, and post: p = 0.002). However, both the CRT and CRT&WL groups significantly improved from pre- to post-test (CRT: p = 0.03, 9.2%, d = 0.53); CRT&WL: p = 0.002, 17.6%, d = 1.00) (Figure 3).

Figure 3 near here

For the standing overhead press, all groups were similar at baseline but the CRT and CRT&WL groups scored significantly better than the CON group at the mid- (p = 0.01 and 0.04) and post-test (p = 0.04 and 0.002). Each training group significantly improved their score from pre- to mid- (CRT = $p < 0.01$, 31.3%, d = 0.91; CRT&WL = $p < 0.05$, 26.8%, d = 0.75) and pre- to post-test (CRT = $p < 0.01$, 40.1%, d = 1.12; CRT&WL = $p \leq 0.001$, 33.3%, d = 1.35) (Figure 4A). There were no significant between-group differences or within-group changes for the front support with chest touches (all $p > 0.05$) (Figure 4B). For the body weight squat, there were no between-group differences at any time points, but the CON group significantly improved from pre- to post-test ($p < 0.01$, 37.1%, d = 0.71) (Figure 4C). For the lunge, the CRT and CRT&WL

groups scored significantly better than the CON group at baseline ($p \leq 0.001$ and 0.003, respectively), but there were no between-group differences at any other time point and no significant within-group changes (Figure 4D). For the suspended row, both the CRT&WL and CON groups significantly improved performance over the first half of the intervention (CRT&WL = $p < 0.01$, 51.0%, $d = 1.24$; CON = $p < 0.01$, 21.0%, $d = 0.53$) and the CRT&WL group decreased in performance over the last half ($p < 0.05$, -13.2%, $d = -0.74$) (Figure 4E). Lastly, the CRT group scored significantly better than the CRT&WL group ($p = 0.03$) and CON group ($p = 0.002$) on the push-up at the mid-test, but there were no significant within-group changes for any group (Figure 4F).

Figure 4 near here

Discussion

This study examined the effects of an academic year of CRT or CRT&WL versus traditional physical education curriculum on measures of jump landing kinematics, interlimb asymmetry of several common field-tests, and resistance training skills of adolescent males. Overall, the findings suggest that both training groups scored significantly better than the CON group on the tuck jump assessment after 14 weeks of training. However, only the CRT group significantly improved tuck jump performance between any two time points and scored better than the CON group after 28 weeks of training. The effects of CRT and CRT&WL on interlimb asymmetry were inconsistent and varied according to test protocol. Furthermore, both CRT and CRT&WL were effective in improving resistance training skill competency, although the inclusion of weightlifting training resulted in a greater percentage improvement than CRT alone.

The CRT group was the only group to significantly improve their tuck jump assessment score. Additionally, the CRT group reduced their score by 1.11 points, which is greater than the typical error of 0.90 and 1.01 identified in pre-PHV and post-PHV groups, respectively (38). However, despite a reduction for the CRT&WL group, their improvement of 0.60 points was lower than the previously mentioned typical errors (38), which suggests their improvement could simply be due to natural variation in tuck jump performance. In contrast to the findings from this study, a 10-week intervention using body weight exercises failed to improve tuck jump assessment scores more than a control group in similarly aged female athletes (20). The current study included 28 weeks of training with loads in excess of body weight, which indicates that longer duration training interventions using greater external loads may be necessary to significantly improve tuck jump assessment scores. Interestingly, CRT&WL training did not improve tuck jump assessment scores despite significant gains in resistance training skill. This suggests that improvements in resistance training skill may not transfer to more intense movements, such as repetitive jump landings. Therefore, practitioners can include a combination of traditional resistance and plyometric training to improve jump landing kinematics.

In general, no differences were seen in asymmetry measures between time points or groups. Horizontal jump asymmetry of the participants in the present study are comparable to the 7% found in circa-PHV males in a previous cross-sectional study (41). Interestingly, the CON group decreased their single-leg horizontal jump asymmetry more than both training groups over the course of the study. One factor that could have contributed to this finding was that the training groups were comprised exclusively of athletes, whereas the control group was a mixture of athletes and non-athletes. Rugby and soccer are common sports in New Zealand, so the athletes in the training groups may have propagated their asymmetry over the course of the intervention from the repetitive kicking exposure whereas single-leg horizontal jump asymmetry naturally decreased for the CON group with regular physical education curriculum. Despite the greater reduction in asymmetry seen in the CON group, each group's mean horizontal jump asymmetry was < 10% at each time point, which is below the common threshold used for return-to-play scenarios in youth athletes (37). Therefore, neither of the groups as a whole were considered at greater risk of injury as a result of abnormally high asymmetry. Although asymmetry of single-leg horizontal jumps is relatively low compared to asymmetry during sprinting (14.7-20.2%) (43) and single-leg vertical jumps of similar aged athletes (9.0-15.0%) (6, 41), it is potentially less sensitive to detect asymmetry above established thresholds. Nonetheless, a single-leg jump assessment requires very little equipment and is therefore still a valuable tool for practitioners to detect changes in asymmetry over time. Since much of the existing research examining asymmetry in youth males is cross-sectional in nature (6, 39-41, 43), further research examining the effects of training programs on lower-extremity asymmetry is needed.

The RTSQ improved the most in the CRT&WL group, whereas the CRT group experienced similar moderate improvements as the CON group. This may be due in part to the nature of weightlifting movements, which require greater neuromuscular coordination than traditional resistance training exercises (16). Despite the differences in raw RTSQ improvements (CRT = 3.3; CRT&WL = 5.0; CON = 3.0), each group improved their RTSQ more than the typical error of 2.5 reported by Lubans et al. (25), which suggests these changes were not due to natural variation. However, only the training groups improved significantly from pre- to post-test, which indicates the efficacy of a school curriculum training program that includes variations of the key movement patterns included in the RTSB (e.g. squat, push-up, standing overhead press, and core stability exercises). Only one other study has examined the effects of an intervention on resistance training skill competency (47). The intervention group in that study improved their RTSQ more than a control group after a 20-week intervention. However, the participants were adolescent boys at risk of obesity with a baseline RTSQ of ~31 points, which was lower than all three groups in the current study (32-39 points). Thus, RTSQ may be more sensitive to improvements due to the health status and low baseline scores of those participants. Based on the findings of the current study, school-based resistance training programs may improve resistance training skill competency, although the inclusion of weightlifting training may provide additional benefits due to the greater technical and coordinative demand of the exercises.

When examining individual skills, both training groups significantly improved the standing overhead press and were significantly higher than the CON group at the mid- and post-test. Additionally, the training groups improved more than the typical error of 1.0 (25) for the standing overhead press (CRT = 2.0; CRT&WL = 1.8), whereas the CON group did not (CON = 0.5). One possible reason for the large improvement in standing overhead press is that it is a less common movement pattern than the other RTSB skills that occur naturally during sport or physical education curricula, such as squatting or lunging. Therefore, the novelty and inclusion of overhead exercises such as standing dumbbell and barbell overhead presses, push presses, push jerks, and split jerks in the training program likely contributed to the large improvements seen in both training groups. The previously mentioned study that measured resistance training skill competency over a 20-week intervention did not include a breakdown of individual skill improvement (47), so there is no comparative literature available that has tracked changes in individual skills after resistance training programs. Further research investigating the effects of training programs on resistance training skill is needed to validate these findings, as well as determine if training responses are similar in different populations.

In summary, the results of this study showed that CRT improved tuck jump scores more than CRT&WL and regular physical education curriculum. Additionally, both CRT&WL and CRT significantly improved resistance training skill after an introductory resistance training program. Cumulatively, practitioners can use a combination of traditional resistance training, plyometric, and weightlifting training to reduce injury risk factors associated with jump landings and improve resistance training skill competency.

PRACTICAL APPLICATIONS

The findings of this study suggest that resistance training with or without weightlifting movements may improve resistance training skill competency, particularly for overhead movements. Combined resistance and plyometric training may provide greater improvements in jump landing kinematics. However, the inclusion of weightlifting movements within the resistance training program may provide greater improvements in movement skill, possibly due to the increased complexity of these lifts. Despite the benefits of weightlifting training, practitioners should ensure that young athletes are exposed to appropriate progression, with technical competency never compromised in the pursuit of lifting greater loads. This study highlights the effectiveness of a comprehensive resistance training program integrated into secondary school curriculum by a certified and qualified strength and conditioning coach.

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Figure 1. Isometric mid-thigh pull setup.

Figure 2. CRT = combined resistance training; CRT&WL = combined resistance training & weightlifting; CON = control; *significant within-group change for CRT group ($p \leq 0.05$), **($p \leq 0.01$); a = CRT group significantly higher than CON group ($p \leq 0.05$); b = CRT&WL group significantly higher than CON group ($p \leq 0.05$).

Figure 3. CRT = combined resistance training; CRT&WL = combined resistance training & weightlifting; CON = control; *significant within-group change for CRT group ($p \leq 0.05$); † significant within-group change for CRT&WL group ($p \leq 0.05$); a = CRT group significantly higher than CON group ($p \leq 0.05$); b = CRT&WL group significantly higher than CON group ($p \leq 0.05$); c = CRT group significantly higher than both groups ($p \leq 0.05$).

Figure 4. A) standing overhead press; B) front support with chest touches; C) body weight squat; D) lunge; E) suspended row; F) push-up; CRT = combined resistance training; CRT&WL = combined resistance training & weightlifting; CON = control; **significant within-group change for CRT group ($p \leq 0.01$); † significant within-group change for CRT&WL group ($p \leq 0.05$); ††† ($p \leq 0.001$); ‡‡ significant within-group change for CRT&WL group ($p \leq 0.01$); a = CRT group significantly higher than CON group ($p \leq 0.05$); b = CRT&WL group significantly higher than CON group ($p \leq 0.05$).

Table 1. Anthropometric data (mean ± standard deviation) for pre-, mid- and post-test.

	CRT (n = 21)			CRT&WL (n = 19)			CON (n = 27)		
	Pre	Mid	Post	Pre	Mid	Post	Pre	Mid	Post
Height (cm)	165.0 ± 10.2	167.6 ± 10.2	170.0 ± 10.0	168.1 ± 8.4	171.6 ± 7.4	172.9 ± 7.6	165.1 ± 9.3	167.4 ± 8.2	170.2 ± 7.7
Body mass (kg)	55.8 ± 12.4	58.8 ± 12.9	60.9 ± 12.7	56.7 ± 10.9	60.0 ± 11.7	64.2 ± 12.0	56.6 ± 15.1	60.8 ± 15.7	61.2 ± 15.6
Maturity offset (years)	0.0 ± 0.8			0.2 ± 0.8			0.0 ± 0.9		

CRT = combined resistance training; CRT&WL = combined resistance training & weightlifting; CON = control.

Table 2. Training program guidelines for the CRT and CRT&WL groups.

	Term 1	Term 2	Term 3	Term 4
Training weeks	6	8	8	6
Exercises	6	5-6	5	4
Sets	1-3	1-3	1-4	1-4
Reps	8-20	8-12	2-6	2-5
Relative intensity	Low-moderate	Moderate	Moderate-high	Moderate-high
Inter-set rest	1-2 minutes	1-2 minutes	2-3 minutes	2-3 minutes

CRT = combined resistance training; CRT&WL = combined resistance training & weightlifting.

Table 3. Percentage asymmetry measures and within-group effect sizes for the single-leg horizontal jump, isometric midthigh pull, and modified Star Excursion Balance Test.

	CRT			CRT&WL			CON		
	Asymmetry %			Asymmetry %			Asymmetry %		
	Pre	Mid	Post	Pre	Mid	Post	Pre	Mid	Post
Single-leg horizontal jump (m)	7.1 ± 5.1	5.7 ± 4.0	6.3 ± 4.6	6.1 ± 3.7	5.4 ± 6.7	5.4 ± 4.9	8.9 ± 6.9	7.4 ± 7.6	5.8 ± 5.9
Isometric mid-thigh pull (N)	17.2 ± 13.5	17.5 ± 11.9	12.8 ± 8.9	15.2 ± 9.6	21.0 ± 13.9	12.3 ± 8.2[b]	17.2 ± 13.3	15.7 ± 9.0	18.4 ± 12.8
Anterior reach (cm)	4.0 ± 3.4	3.4 ± 3.4	2.7 ± 2.5	6.3 ± 4.5	4.8 ± 4.2	5.4 ± 4.6	4.8 ± 4.5	7.0 ± 6.8	4.0 ± 3.9[b]
Posteromedial reach (cm)	4.6 ± 3.8	3.9 ± 2.7	2.8 ± 2.3	4.9 ± 4.5	3.9 ± 3.2	3.6 ± 3.2	4.6 ± 4.2	3.5 ± 2.8	5.0 ± 5.2
Posterolateral reach (cm)	4.8 ± 3.4	2.0 ± 2.3[a]	3.1 ± 3.4	3.9 ± 3.6	3.1 ± 2.7	3.8 ± 3.5	4.6 ± 3.3	1.9 ± 2.3[a]	2.4 ± 2.1[a]

[a] significantly less than pre-test ($p < 0.05$); [b] significantly less than mid-test ($p < 0.05$).


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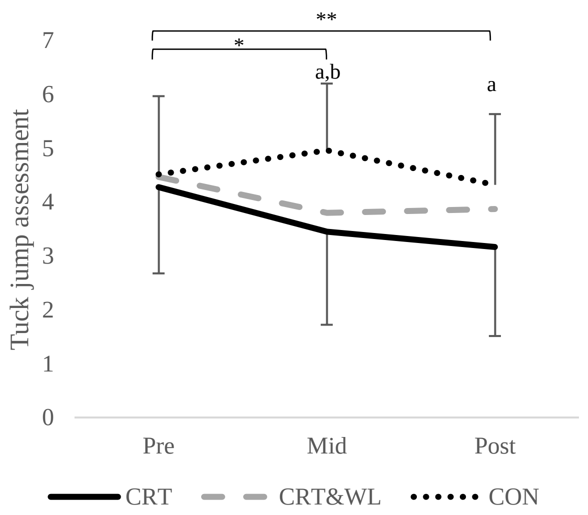
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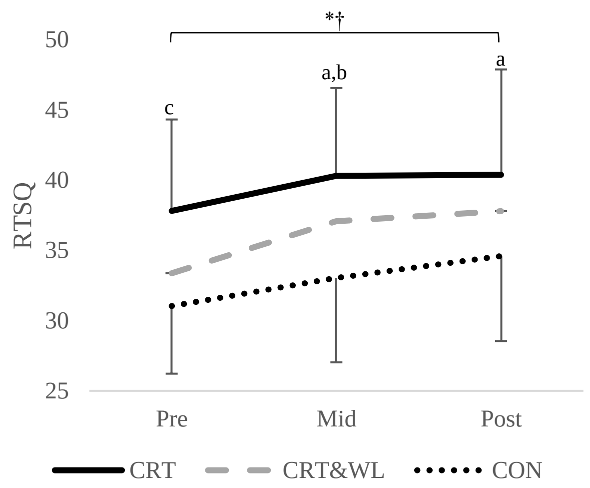
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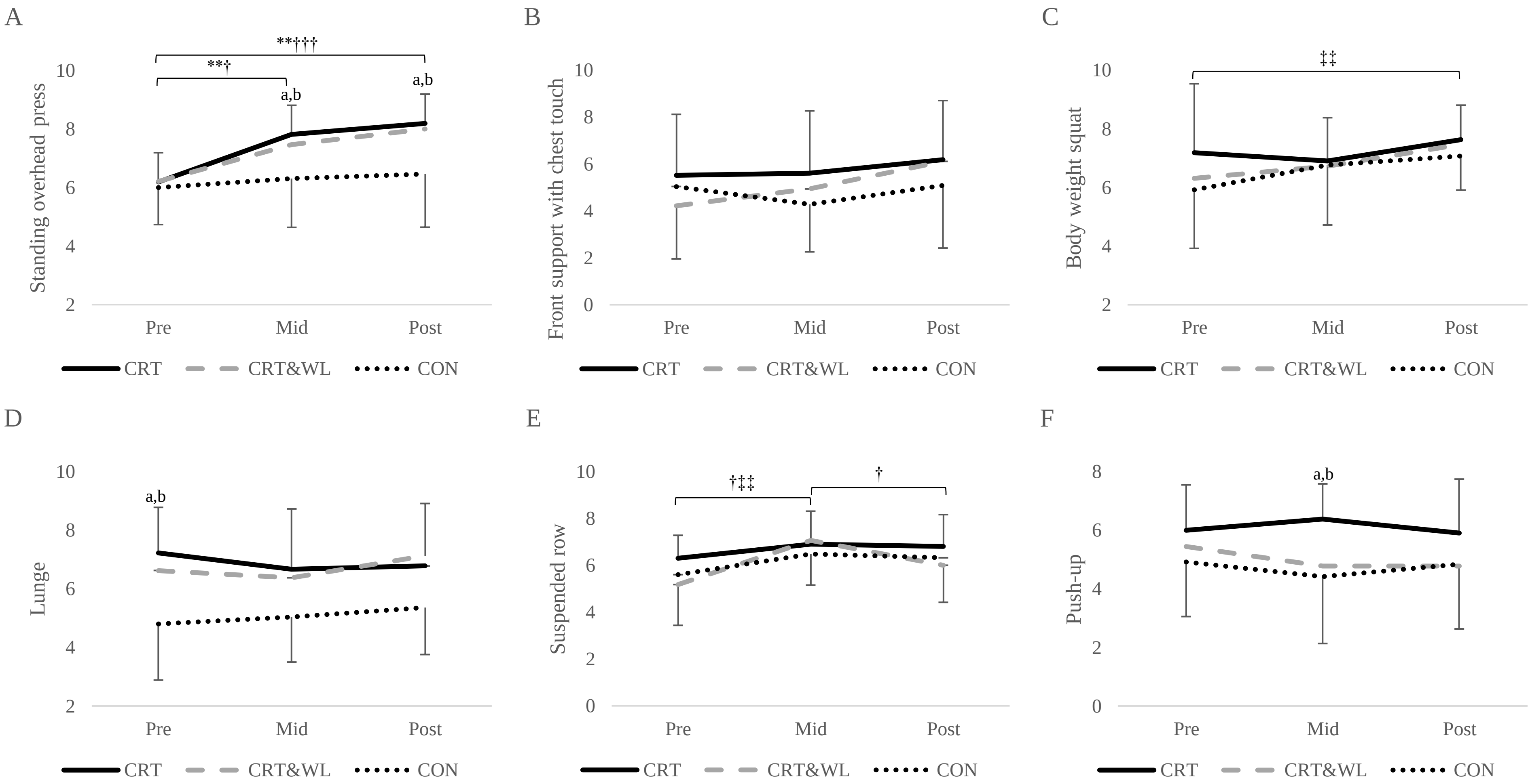
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Front support with chest touch
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Body weight squat
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CRT&WL
CON
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Lunge
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8
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CON
E
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Suspended row
10
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a,b
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