The Effect of High *vs*. Moderate-Intensity Resistance Training on Strength, Power and Muscle Soreness in Male Academy Soccer Players

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Abstract

The aims of this study were to investigate the impact of high-intensity, low-volume (HRT) *vs.* moderate-intensity, high-volume resistance training (MRT) *vs.* soccer training only (CON) on changes in strength, power, and speed, and to compare delayed onset muscle soreness (DOMS) between groups in male academy soccer players (ASP). Twenty-two ASP (age: 18±1 years) were assigned to either HRT (*n*=8), MRT (*n*=7) or CON (*n*=7). HRT completed 2 sets of 4 repetitions parallel back squat (PBS) repetitions at 90% 1RM, while MRT performed 3 sets of 8 repetitions PBS repetitions at 80% 1RM, both once a week for six-weeks in-season, alongside regular soccer training. All groups completed the following pre- and post-training assessments: 3RM PBS; bilateral vertical and horizontal countermovement jumps (CMJ); squat jump (SJ); 30m sprint. DOMS was assessed via visual analogue scale throughout training. HRT and MRT experienced similar increases compared to CON in absolute PBS 3RM (p<0.001), SJ height (p=0.001), CMJ height (p=0.008) following training. There was a greater increase in PBS 3RM relative to body mass following HRT than MRT and CON (p=0.001) and horizontal CMJ distance improved in HRT but not in MRT or CON (p=0.011). There was no change in 10m, 20m or 30m sprint performance in any group. HRT volume was 58±15% lower than that of MRT (p<0.001) and DOMS measured throughout training did not differ between groups (p=0.487). These findings suggest that one HRT session a week may be an efficient method for improving strength and power in ASP in-season with minimal DOMS.

INTRODUCTION

Soccer is an intermittent sport requiring high-intensity dynamic movements, such as acceleration, sprinting, change of direction (COD) and jumping (3, 28). Under 18 year-old academy soccer players complete an average of 81 ± 18 powerful actions during a match, with the most common being initial and leading accelerations (~68), followed by a similar number of sprints (~8) and vertical jumps (~6) (28). Improvement in these key game elements can positively influence performance in professional soccer (10) and related assessment scores can distinguish elite from non-elite performers (27). Based on this evidence, high levels of muscular strength and power are very important in youth soccer (5). Therefore, effective training methods to develop these powerful movements are fundamental to improve performance.

Strength and conditioning (S&C) coaches in youth soccer actively seek to improve these sport specific actions through a variety of training methods, of which resistance training (RT) is a central component (21). Further, men's academy S&C coaches in the UK incorporate 2 ± 1 S&C sessions per week, lasting 45 ± 14 minutes (22). Conclusions from a youth RT meta-analysis suggest that the most effective training frequency to develop strength and power in youth athletes is 2-3 sessions a week, while a single session may maintain established strength levels (18). However, a single RT session per week can be sufficient to improve strength and power performance in those with less experience (19), whereas high-intensity RT may be required with increased training age (33). Moreover, McQuilliam, et al. (22) suggest that limited time is one of the main reasons given by S&C coaches for not incorporating RT into their players' programmes. Thus, the inclusion of just one RT session per week may be perceived as being more practically feasible for some practitioners.

Youth soccer RT interventions that have followed the guidelines of Lesinski, Prieske and Granacher (18) have resulted in increases in soccer-specific athletic actions. When utilising training intensities ≥80% single repetition maximum (1RM) in-season, increases in strength, acceleration, sprint and vertical jump have been reported following eight-weeks' RT (4, 36), with no change in muscle cross-sectional area (14). Consequently, improvements in physical performance were attributed to neural adaptations rather than muscle hypertrophy (14). This is an important consideration, as strength relative to body mass has strong correlations with improvements in acceleration and vertical jump performance (5, 36). Together, this suggests the implementation of RT programmes during the competitive period should be feasible. However, soccer S&C coaches typically implement three sets of eight repetitions at a moderate intensity when aiming to develop strength in-season (22), which would normally be regarded as hypertrophy/strength-endurance training (>6 repetitions at moderate-intensity) rather than training to primarily improve strength (1 to 6 repetitions at high-intensity) (13, 17). Further, the two main limiting factors reported by coaches for incorporating RT into soccer training are time constraints and concerns of athletes experiencing delayed onset muscle soreness (DOMS) following RT (22). As the volume of RT may dictate both the time taken to complete a RT session and the degree of DOMS experienced by the athlete, limiting these factors may help maximise performance gains with minimal impact on time to complete soccer-specific training, while also mitigating DOMS.

Beyond prescribing training volume and intensity, a key variable to consider is exercise selection and specific variations. Previously, McQuilliam, et al. (22) reported bi-lateral squatting patterns were the most common movement prescribed by soccer academy S&C coaches (85% responders). However, variations within this group of movements may impact training adaptations, for example, the range of movement implemented. Each of the cited training studies have implemented the half-squat, characterised by (80 – 100° knee flexion). This is potentially due to participants having inadequate technique, and concerns regarding lack of mobility and injury (9), or the belief that it is a more sport-specific range of motion (32). However, full- (135 – 140° knee flexion) and parallel- (110 -120° knee flexion) squats have been shown to improve vertical jump, acceleration, and load-velocity characteristics more so than half- and quarter-squats (2, 15, 31).

Consequently, the primary aim of this study was to investigate the impact of high-intensity, low-volume RT (HRT) vs. the moderate-intensity, high-volume RT (MRT) approach commonly utilised in soccer (22), using parallel squat training, on changes in strength, power and speed in academy soccer players, compared to pitch-based soccer training only. A second aim was to compare DOMS between the three groups. We hypothesized that performance benefits would be similar between HRT and MRT, but that HRT would experience less DOMS due to a lower training volume (making training session duration shorter), thus being a more effective training method.

METHODS

Experimental approach to the problem

Participants in all three groups completed the same pre- and post-training assessments, which comprised maturity offset (25), 30 m sprint, squat jump (SJ), bilateral vertical and horizontal countermovement jumps (CMJ), and 3RM back squat. Both HRT and MRT completed a six-week in-season strength training programme alongside regular soccer training, with one session a week on match day minus two (two days prior to a competitive fixture). CON performed their regular soccer training for the six-week period.

Subjects

To be eligible to take part, participants had to be young, healthy men, part of a regular soccer-training programme, free from lower-body injuries, and be able to attend all training sessions in this study. Participants were recruited from an education and soccer college, which incorporated three soccer training sessions and at least one soccer match per week against professional soccer academies. An *a priori* power calculation was performed to estimate the required sample size using G*Power software (v3.1.9.6, Heinrich-Heine-Universität

Düsseldorf, Düsseldorf, Germany). Given the mixed design of this study, a total sample of 21 participants (7 per group) was required to detect a medium (group × time interaction) effect size (η_p^2= 0.12; α: 0.05; power: 0.80). Fifty-one soccer players volunteered to participate in the study and provided written consent prior to start of the intervention. Ten players withdrew due to injury sustained during soccer training/match-play (not as a consequence of the study) and a further 20 could not complete the post-training assessments due to the COVID-19 pandemic. A total of 22 participants completed the study (age = 16 to 19 years; height = 178.5 ± 6.5 cm; body mass = 71.4 ± 7.4 kg) and included one goalkeeper, six defenders, six midfielders and eight forwards. All took part in formal soccer training (eight hours per week) plus one or two competitive fixtures each week. Participants had prior experience of lower-body RT (1-3 years) but not of high-intensity training (>70 % 1RM). Participants were randomly assigned to either a high-intensity RT group (HRT: *n* = 8), moderate intensity RT group (MRT: *n* = 7) or a soccer only control group (CON: *n* = 7). Soccer training for all groups included four pitch training sessions per week, ranging from 60 to 120 minutes, plus one competitive match. Groups were matched according to their baseline 3RM, age, height and body mass. The groups in the final sample differed in age and relative strength at baseline but did not differ regarding baseline body mass (p = 0.197), height (p = 0.068) or absolute back squat strength (p = 0.063, Table 1). Final groups (Table 1). All participants provided written informed consent prior to taking part in the study, which was approved by the Liverpool John Moores University Research Ethics Committee and complied with the Declaration of Helsinki.

*****Table one*****

Experimental approach to the problem

Participants in all three groups completed the same pre- and post-training assessments, which comprised maturity offset (25), 30 m sprint, squat jump (SJ), bilateral vertical and horizontal countermovement jumps (CMJ), and 3RM back squat. Both HRT and MRT completed a six-week in-season RT programme alongside regular soccer training, with one session a week on match day minus two (two days prior to a competitive fixture). HRT completed two sets of four repetitions of parallel back squat at 90% 1RM (estimated from 3RM), while the MRT group performed three sets of eight repetitions of parallel back squat at 80% 1RM. CON performed their regular soccer training for the six-week period.

Testing methodology

Participants attended two separate testing days (with a minimum of 48 hours between each session) before and after the six-week intervention period. To reduce the impact of fatigue, participants were instructed to abstain from high-intensity exercise for a minimum of 24 hours prior to each testing session.

Testing Day One

The first session comprised measurements of body mass (Digital flat scale, Seca, Hamburg, Germany) and standing and sitting height (Portable stadiometer, Seca, Hamburg, Germany), in order to calculate maturity offset using the previously proposed equation by Mirwald, et al. (25).

$$Maturity\ Offset = -29.769 + 0.0003007 \cdot$$
$$Leg\ Length\ and\ Sitting\ Height\ interaction - 0.01177 \cdot$$
$$Age\ and\ Leg\ Length\ interaction\ x\ 0.01639 \cdot Age\ and\ Sitting\ Height\ interaction +$$
$$0.445 \cdot Leg\ by\ Height\ ratio$$

Participants were familiarised with each jump assessment prior to testing. Participants completed three trials of each jump type, with 30 s rest between jumps, and approximately 5 min rest between jump types. For the SJ and vertical CMJ, the depth participants lowered themselves to was self-selected, while participants were instructed to jump as high as possible, fully extending through hip, knee and ankle, while keeping their arms akimbo to eliminate the effect of arm swing on performance. Participants were instructed to land on the balls of their feet followed by three small bounces on the indoor gym floor. This was done to control jump and landing positions, as jump height was calculated indirectly via flight time (Optojump, Microgate, Bolzano, Italy). This method has been shown to have excellent reliability (intra-class correlation (ICC) = 0.982 – 0.989) and low coefficients of variation (CV = 2.8%) in a similar cohort (11). Horizontal CMJ testing was performed on an outdoor artificial grass surface. With arms akimbo, participants started with both feet behind a straight line and were instructed to jump as far as possible. Participants were required to maintain balance upon landing with the measurement taken from the heel of the foot nearest the start line. For each of the three jump types, if the third attempt was the best, participants were given additional attempts until results no longer increased. The peak value was used in subsequent analysis.

All participants completed a 15-minute standardised warm-up prior to sprint testing. The warm-up consisted of light jogging and running drills (5 minutes), dynamic bodyweight movements (split squats, lunges, glute bridge, hamstring walk outs; 2 sets of 6 repetition each), submaximal sprints and decelerations (5 minutes). Participants completed three 30 m sprints on an outdoor 3G pitch, wearing appropriate soccer training kit. Sprints started in a static, split stance position with no countermovement behind the start line. Timing gates (TCi System, Brower, Salt Lake City, USA) were placed 1 m, 11 m, 21 m and 31 m from the start line. Participants were instructed to sprint beyond the final gate to ensure no slowing down prior to completion. There was a three-minute rest between each sprint for full recovery (24). The fastest split for each sprint was used in subsequent analysis. Due to technical issues, sprint data were unable to be recorded in three participants, so sample size for this assessment was HRT, n=6; MRT, n=7; CON, n=6. These sprint distances have previously been reported to have good reliability (10 m, ICC = 0.78 (95% confidence intervals: 0.57 – 0.89); 20 m, ICC = 0.78 (0.85 – 0.97)) and low coefficients of variation (10 m = 2.4%; 20 m = 1.4%) in academy soccer players (7).

Testing Day Two

Maximal lower limb strength was assessed via 3RM parallel back squat. Prior to the test, participants performed a standardised warm up of 10 repetitions with an unloaded bar, five repetitions with 50% body mass and three repetitions with 75% body mass with loads rounded to the nearest 0.25 kg. All squats were performed to parallel, i.e. where the tops of the thighs were horizontal to the ground (110 -120° knee flexion), with each repetition assessed visually by the investigator. The load lifted was increased following each successful attempt based on the difficulty it was completed with. An attempt was deemed a failure if the participant did not achieve the required depth or was unable to complete a repetition without assistance. Maximum strength testing has been shown to be reliable (ICCs $\geq$ 0.90, CV <10%) assessment of lower body strength irrespective of RT experience and age (12). Testing was visually monitored by the researcher and each participant rested three to five minutes after each attempt (13).

Training Programme

To familiarise all participants with the parallel back squat and ensure that all could complete the exercise safely and with correct technique, participants completed four 30 min sessions over a two-week period prior to baseline testing. Participants were not permitted to start the study until their technique was considered to be appropriate by a National Association for Strength and Conditioning (NSCA)-accredited S&C coach. All RT sessions and testing were led by the same NSCA-accredited S&C coach with a relevant Masters degree and >10 years' coaching experience (SM). Following baseline testing, participants in the training groups completed a once-weekly RT programme, implemented concurrently with regular soccer training on match day minus two. Each squat training session comprised a bodyweight warm-up (10 repetitions of squats, lunges and glute bridges), barbell warm-up sets of 10 repetitions at 20 kg, 8 repetitions at 50% and 5 repetitions at 70% estimated 1RM, as described above, followed by the training protocol. HRT completed two sets of four repetitions at 90% 1RM, while MRT completed three sets of eight repetitions at 80% 1RM to the nearest 0.25 kg. Loads were prescribed by using the Epley equation (1RM= ([0.033 x Repetitions] x Load) + Load) to estimate 1RM strength from the 3RM strength test (8). Both groups had three minutes' rest between sets (13). Squat technique and depth were monitored by the researcher and load was increased when the participant could safely and correctly complete the prescribed load.

Monitoring DOMS and training load

Throughout the intervention, participants were asked to report subjective muscle soreness for the lower limbs prior to, immediately after, 24 hours after, and 48 hours after each training session using a visual analogue scale (VAS). The scale ranged from 0 cm, referring to no soreness, up to 10 cm, which would indicate extreme muscle soreness (1). At the 24 hour and 48-hour post training time points, participants reported their lower body muscle soreness via a Google form using the same standard VAS. Participants were then asked to further specify any sites of muscle soreness they could identify using a free-text box in the Google form. RT volume load was calculated by multiplying repetitions by sets and external load lifted.

Statistical Analysis

Following pre-testing, the smallest worthwhile change was calculated based on Cohen's effect size principle, with 0.2 representing a small effect size (37). Statistical analysis was completed using SPSS (SPSS 26, IBM, Armonk, USA). One-way between groups ANOVAs were used to detect differences between groups at baseline, and also to detect between group differences in % change in performance variables. Two-way mixed ANOVAs were used to assess the effect of the interventions on performance and monitored metrics. If a significant interaction effect between group and time was found, a post-hoc one-way ANOVA (with Bonferroni corrected pair-wise comparisons) was used to determine which group(s) increased more than the other(s). DOMS data from week three were excluded from analysis due to an external match fixture being played the day prior to the training session, which may have influenced DOMS results that week. All data are expressed as mean ± standard deviation (SD) and statistical significance was set at $p < 0.05$.

RESULTS

Body mass

There was a significant main effect for time ($F_{1, 19} = 6.08$, $p = 0.023$) with no effect for group ($F_{2, 19} = 2.23$, $p = 0.135$), but there was an interaction between time and group ($F_{2, 19} = 6.97$, $p = 0.005$). Post-hoc paired t-tests with Bonferroni correction demonstrated that only MRT increased pre- (75.1 ± 8.4 kg) to post-intervention (77.4 ± 9.5 kg, $p = 0.029$) compared to HRT (pre: 68.2 ± 6.5 kg, post: 68.7 ± 6.4 kg, $p = 0.049$) but not CON (pre: 71.6 ± 6.4 kg, post: 71.1 ± 6.0 kg, $p = 0.216$).

Height

There was a main effect of time ($F_{1, 19} = 17.52$, $p = 0.001$), HRT increased from 174.8 ± 5.8 cm to 175.4 ± 6.0 cm, MRT from 182.5 ± 6.9 cm to 183.3 ± 6.7 cm and CON from 178.8 ± 5.1 to 179.8 ± 5.1 cm. There was no main effect of group ($F_{2, 19} = 3.22$, $p = 0.063$) and no interaction between time and group ($F_{2, 19} = 0.31$, $p = 0.735$).

Absolute Strength

There was a main effect for time ($F_{1, 19} = 89.64$, $p < 0.001$, Fig 1a), no main effect for group ($F_{1, 19} = 1.00$, $p = 0.38$) but there was an interaction between group and time ($F_{1, 19} = 18.02$, $\eta_p^2 = 0.655$, $p < 0.001$). Post-hoc paired t-tests with Bonferroni correction demonstrated that absolute back squat strength increased in HRT ($t_7 = -7.77$, $p < 0.001$, $d = 0.80$) and MRT ($t_6 = -6.49$, $p = 0.001$, $d = 1.35$) but not in CON ($t_6 = -1.27$, $p = 0.253$, Fig 1a). Pre-intervention testing established the smallest worthwhile change for estimated 1RM to be 3.39 kg. A one-way between groups ANOVA ($p < 0.001$) revealed that the % change in absolute strength was greater in HRT (+17.1 ±7.5%, $p = 0.025$) and MRT (+29.1 ± 15.8%, $p < 0.001$) compared to CON (+1.7 ± 3.4%) but did not differ between HRT and MRT ($p = 0.100$).

Relative Strength

There was a main effect for time ($F_{1, 19} = 76.23$, $p < 0.001$, Fig 1b), for group ($F_{1, 19} = 4.07$, $p = 0.034$) and there was an interaction between time and group ($F_{1, 19} = 11.53$, $\eta_p^2 = 0.548$, $p = 0.001$). Post-hoc paired t-tests with Bonferroni correction demonstrated that relative back squat strength increased in HRT ($t_7 = -6.11$, $p < 0.001$, $d = 1.31$) and MRT ($t_6 = -6.64$, $p = 0.001$, $d = 1.11$) but not CON ($t_6 = -1.53$, $p = 0.176$, Fig 1b). Pre-intervention testing established the smallest worthwhile change to be 0.05 kg relative to body mass. A one-way between groups ANOVA ($p = 0.001$) revealed that the % change in relative strength was greater in HRT (+16.2 ± 8.1%, $p = 0.035$) and MRT (+25.2 ± 14.1%, *p* ¸0.001) compared to CON (+2.4 ± 3.9%) but did not differ between HRT and MRT ($p = 0.255$).

*****Figure one*****

Squat jump (SJ) height

There was no main effect for time ($F_{1, 19} = 4.34$, $p = 0.051$), or group ($F_{1, 19} = 0.19$, $p = 0.826$) but there was interaction between time and group ($F_{2, 19} = 11.33$, $\eta_p^2 = 0.544$, $p = 0.001$, Fig

2a). Post-hoc paired t-tests with Bonferroni correction demonstrated that SJ height increased in HRT (t_7 = -2.60, p = 0.035, d = 0.71) and MRT (t_6 = -3.61, p = 0.011, d = 0.65) and decreased in CON (t_6 = 2.55, p = 0.044, d = 0.44, Fig 2a). Pre-intervention testing established the smallest worthwhile change to be 0.8 cm. A one-way between groups ANOVA ($p < 0.001$) revealed that the % change in SJ height was greater in HRT (+6.1 ± 6.8%, p = 0.006) and MRT (+10.8 ± 7.2%, p <0.001) compared to CON (-6.5 ± 6.6%) but did not differ between HRT and MRT (p = 0.621).

Vertical CMJ height

There was no main effect for group ($F_{1, 19}$ = 0.55, p = 0.587) but there was a main effect for time ($F_{1, 19}$ = 6.42, p = 0.020) and an interaction between time and group ($F_{2, 19}$ = 6.33, η_p^2 = 0.400, p = 0.008). Post-hoc paired t-tests with Bonferroni correction demonstrated that CMJ height increased in HRT (t_7 = -3.81, p = 0.007, d = 0.86) and MRT (t_6 = -4.23, p = 0.005, d = 0.70) but not in CON (t_6 = 1.02, p = 0.346, Fig 2b). Pre-intervention testing established the smallest worthwhile change to be 0.9 cm. A one-way between groups ANOVA (p = 0.010) revealed that the % change in CMJ height was greater in HRT (+8.8 ± 8.2%, p = 0.027) and MRT (+10.0 ± 6.4%, p = 0.018) compared to CON (-4.0 ± 10.4%) but did not differ between HRT and MRT (p = 1.000).

Horizontal CMJ distance

There was no main effect for group ($F_{1, 17}$ = 0.96, p = 0.405) but there was a main effect for time ($F_{1, 19}$ = 29.16, $p < 0.001$) and an interaction between group and time ($F_{2, 19}$ = 6.02, η_p^2 = 0.415, p = 0.011, Fig 2c). Post-hoc paired t-tests with Bonferroni correction demonstrated that horizontal CMJ distance increased in HRT (t_6 = -6.40, p = 0.001, d = 1.12) but not MRT (t_5 = -1.91, p = 0.114) or CON (t_6 = -1.36, p = 0.223, Fig 2c). Pre-intervention testing established the smallest worthwhile change to be 3.18 cm. A one-way between groups ANOVA (p = 0.017) revealed that the % change in CMJ distance was greater in HRT (+11.3 ± 5.3%, $p = 0.231$) compared to CON (+1.9 ± 3.9%). There was no difference between MRT and HRT (+5.6 ± 7.1%, $p = 0.231$) or MRT and CON ($p = 0.744$)

*****Figure two*****

10 m Sprint time

There was no main effect for group ($F_{1, 17} = 1.59$, $p = 0.235$), time ($F_{1, 17} = 1.49$, $p = 0.239$) or interaction between group and time ($F_{1, 17} = 2.67$, $\eta_p^2 = 0.239$, $p = 0.098$, Fig 3a). Pre-intervention testing established the smallest worthwhile change to be 0.02 s.

20 m Sprint time

There was no main effect for group ($F_{1, 17} = 2.34$, $p = 0.127$), time ($F_{2, 17} = 3.29$, $p = 0.088$) or interaction between group and time ($F_{2, 17} = 3.13$, $\eta_p^2 = 0.269$, $p = 0.070$, Fig 3b). Pre-intervention testing established the smallest worthwhile change to be 0.03 s.

30 m Sprint time

There was no main effect for group ($F_{2, 17} = 1.45$, $p = 0.262$), time ($F_{2, 17} = 3.29$, $p = 0.088$) or interaction between group and time ($F_{2, 17} = 0.76$, $\eta_p^2 = 0.252$, $p = 0.481$, Fig 3c). Pre-intervention testing established the smallest worthwhile change to be 0.05 s.

*****Figure three*****

Training volume

There was a main effect for group ($F_{1, 13} = 76.35$, $p < 0.001$), time ($F_{5, 65} = 55.86$, $p < 0.001$) and an interaction between group and time ($F_{5, 65} = 20.80$, $p < 0.001$). HRT started with a volume of 633 ± 136 kg, increasing to 700 ± 128 kg, whereas MRT started with initial volume of 1491 ± 287 kg, increasing to 1749 ± 280 kg by week six (Fig 4).

*****Figure four*****

DOMS

Regarding overall lower-limb DOMS, there was no main effect for group ($F_{2,\,110}$ = 0.24, p = 0.784) but there was for time ($F_{2,\,220}$ = 34.62, $p < 0.001$) and a significant interaction between group and time ($F_{2,\,220}$ = 10.71, $p < 0.001$, Fig 5). MRT had the greatest increase from pre- to 24 hours post RT (+2.4 cm; p = 0.38) compared to HRT (+1.6 cm). DOMS decreased from 24 hours to 48 hours to a similar extent in HRT (-0.5 cm; p = 0.231) MRT (-1.0 cm) and (CON -1.05 cm; Fig 5). When comparing the locations of muscle soreness, there were similar frequencies recorded between training groups for gluteus, hamstrings and hip adductors. However, MRT reported more quadriceps soreness counts than HRT did (Fig 6).

*****Figure five*****

*****Figure six*****

DISCUSSION

The aim of this study was to compare the impact of six weeks' in-season high-intensity (low-volume) resistance training (HRT) with moderate-intensity (high-volume) resistance training (MRT) and pitch-based only training (CON) on measures of physical performance in academy soccer players. Following the training intervention period, there were similar increases in absolute and relative strength, squat jump and vertical CMJ performance in HRT and MRT compared to CON (i.e. pitch-based soccer training only). Further, HRT improved horizontal jump distance but there was no change in MRT or CON. Importantly, the increases seen in

HRT were achieved with significantly less training volume and a lesser increase in DOMS compared to MRT. These findings suggest that HRT may be a more efficient and effective training method to increase strength and power in-season in academy soccer players compared to MRT (the main method currently used by S&C coaches in soccer (21)).

Increasing strength, particularly strength relative to body mass, can have a beneficial impact on a range of performance metrics (5). Both HRT and MRT increased absolute and relative strength (Fig 1), which aligns with a similar HRT approach with professional soccer players in-season (34). This is a key finding for academy S&C coaches, who may be restricted to a single session of RT per week (22). Further it is important to note that there were no differences between groups for absolute or relative strength at the start of the intervention (Fig. 1). Based on the results presented here, it is possible to increase strength in academy aged soccer players with a single RT training session per week.

Lower-body power is regularly assessed using jump assessments, with 95% of academy S&C coaches using them in practice (23). In the current study, both HRT and MRT resulted in improvements in SJ (Fig 2), which is in line with previous research in soccer players aged 15-17 years old (14), suggesting that concentric power production improved following training. However, changes in vertical bilateral CMJ following RT have previously shown mixed results in academy soccer players. Chelly, et al. (4) showed no changes following an eight-week high-intensity RT programme. In contrast, Hammami, et al. (14) implemented a comparable RT programme in youth soccer players and saw improvements in bilateral vertical CMJ. The inconsistency between results may be due to Hammami, et al. (14) programming a greater proportion of the training at a higher relative intensity. As bilateral vertical CMJ is a valid indicator of dynamic peak-power (30), and peak-power is the result of force (load) multiplied by velocity, the use of the parallel squat in the present study may explain how both HRT and

MRT improved vertical CMJ and SJ performance. Greater squatting depths are associated with lower absolute loads than seen in a half-squat, which in-turn can increase movement velocity towards the end of the movement (20).

While vertical CMJ assessment is commonplace in soccer, it only assesses power production in a single plane. Horizontal orientated jump assessments may be more appropriate to use in soccer due to the greater hamstring and gluteus activation (29), and their relationship with acceleration and sprint performance (6), which are more common than vertical jumps during under 18 year-old men's academy matches (28). Furthermore, horizontal jumps can be used to predict 10 m and 20 m sprint performance (26). Here, only HRT improved horizontal CMJ (Fig 2), however, none of the groups improved sprint times (Fig 3). This was surprising, as both HRT and MRT increased absolute and relative strength, and change in strength correlates with improvement in acceleration performance (36). This may be due to the technical element of sprint performance, as horizontal jump performance predicts only 66% of 10 and 20 m performance. Further, there may be a time delay between the increases in strength and transference into powerful actions (35). Therefore, other factors may have limited the transfer of the greater power production into faster sprint performance (26). Alternatively, it is possible that the relatively large inter-subject variability in sprint performance within a soccer squad, coupled with the fact that our sample for this particular assessment (n = 19) was lower than the estimated minimal sample required (n = 21), prevented us from detecting a group × time interaction. In fact, post-hoc power calculations revealed a statistical power of ~50% for the sprint tests, suggesting the study was underpowered regarding changes in sprint performance. For all other variables, however, statistical power was >80%, suggesting the study was indeed statistically powered to detect group × time interactions regarding changes in strength and (vertical and horizontal) CMJ performance.

As previously reported by McQuilliam, et al. (22) DOMS following RT was a key concern of 54% S&C coaches working with a variety of soccer squads. This may have been a result of the training volumes coaches were prescribing in-season, as shown by the greater DOMS scores with MRT compared to HRT (Fig 5). The lower limb DOMS 24 hours and 48 hours following a HRT (low-volume) session may increase the feasibility of conducting HRT in-season in academy soccer players. An unexpected finding were the specific sites where soccer players reported feeling DOMS following their respective RT programmes. While distribution of the most common sites of DOMS were similar between HRT, MRT and CON, MRT resulted in participants more regularly reporting quadriceps DOMS (Fig 6). While many of the performance tests showed similar improvements between HRT and MRT, it is important to note that HRT achieved these with 58% less volume load. When volume load is matched, Uchida, et al. (38) showed no differences in DOMS or plasma creatine kinase following training at 50%, 75%, 90% or 110% 1RM. This suggests that training volume, as opposed to training intensity, may help explain the lower DOMS seen following HRT, further suggesting it may be a more appropriate RT approach in academy soccer players in-season. Further, this low-volume HRT approach would take less time to complete, thus making it even more attractive to S&C coaches, who report limited time as one of the main restrictions regarding the incorporation of RT into youth soccer training programmes (21).

A limitation of this study is the absence of training load information. An important factor that may have influenced the outcomes of this study, particularly the subjective muscle soreness results, is the pitch-based load within the wider training programme. Soccer training alone can result in muscle damage and soreness, particularly when large volumes of high-speed running are involved due to the high-eccentric forces during ground contact (16). Therefore, this may help explain why subjective muscle soreness increased in the control group in the days following the RT sessions. Finally, match fixtures changed frequently, and on two occasions, there were two fixtures during the week. This resulted in RT not being performed on the same training day (match day minus two) for those weeks. While this may be considered a limitation, situations like this reflect those in professional soccer clubs and may actually strengthen the external validity of the study findings.

PRACTICAL APPLICATIONS

To conclude, six weeks' low-volume, high-intensity (90% 1RM) RT, and high volume, moderate-intensity (80% 1RM) RT both led to improvements in lower-limb strength and power in academy soccer players in-season compared to pitch-based soccer training only. Importantly, the high-intensity group achieved this with 58% less training volume than the moderate-intensity group (Fig 4), and similar muscle soreness to soccer training alone in the subsequent days after each training bout. These findings suggest that high-intensity, low-volume resistance training may be a more efficient and effective training method for academy soccer players in-season than the most common training prescription currently used by coaches in soccer (i.e. moderate-intensity, high-volume resistance training). Future studies should investigate the medium- to long-term effect of high-intensity, low-volume resistance training on the physical development of youth (men and women) soccer players.

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Data availability statement

The authors confirm that the data supporting the findings of this study are available within the article.

Disclosure statement

The authors report no conflicts of interest and the results of the present study do not constitute endorsement of the product by the authors or the NSCA.

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Table 1: Participant characteristics

	HRT (n=8)	MRT (n=7)	Control (n=7)
Chronological age (years)	18 ± 1	18 ± 1	19 ± 1
Body mass (kg)	68.2 ± 6.5	75.1 ± 8.4	71.6 ± 6.4
Height (cm)	174.8 ± 5.8	182.5 ± 6.9	178.8 ± 5.13
Maturity offset	2.76 ± 0.76	2.82 ± 0.95	3.87 ± 3.93*
Estimated 1RM (kg)	89.24 ± 18.72	78.50 ± 16.09	99.35 ± 7.53
1RM relative to body mass	1.3 ± 0.2	1.1 ± 0.2	1.4 ± 0.1

1RM, single repetition maximum.

*higher than HRT and MRT

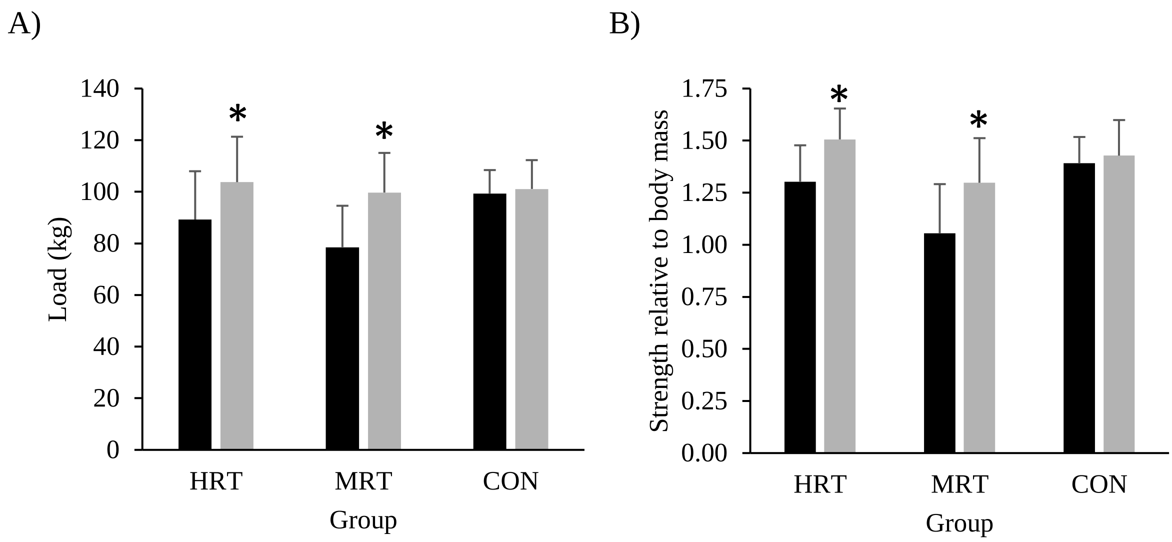


Figure 1: Changes in estimated one repetition maximum (1RM) back squat strength (A) and 1RM relative to bodyweight (B) from pre- (black bars) to post-training intervention (grey bars). HRT, high-intensity resistance training group; MRT, moderate-intensity resistance training group; CON, control group; * significantly different from pre-testing.

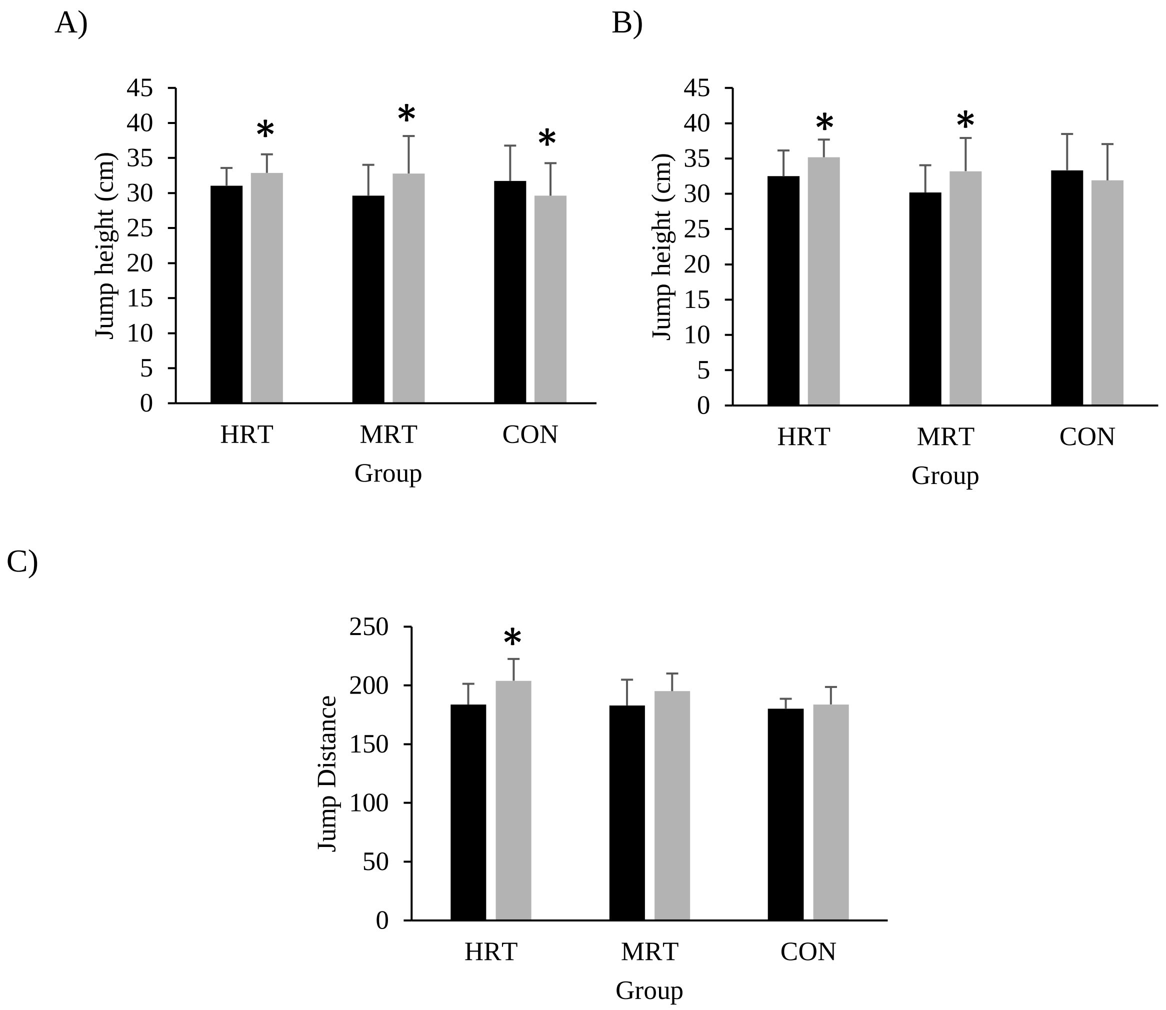
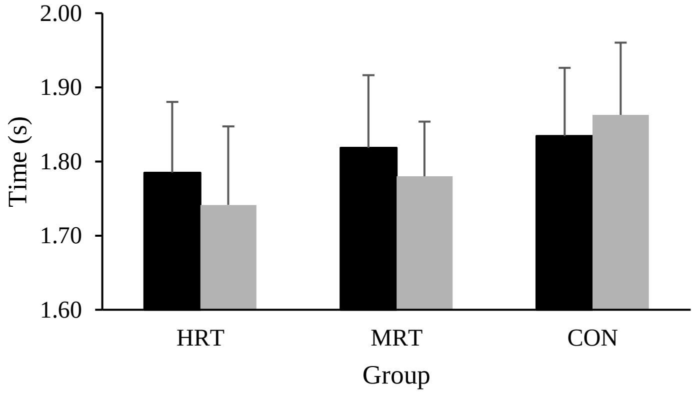
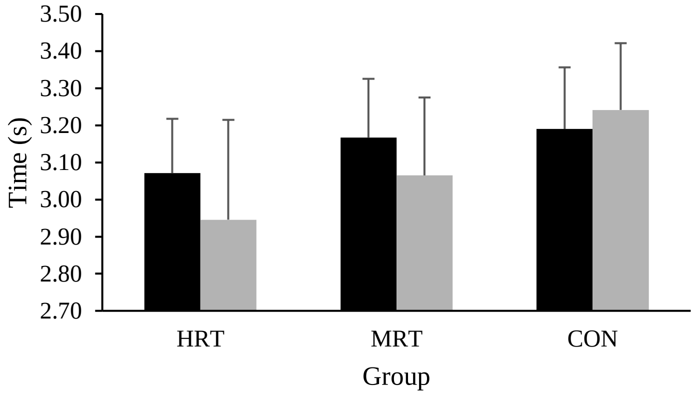


Figure 2: Changes in squat jump (A), countermovement jump (B) and horizontal jump (C) from pre- (black bars) to post-training intervention (grey bars); HRT, high-intensity resistance training group; MRT, moderate-intensity resistance training group; CON, control group; * significantly different from pre-testing.

A)



B)



C)

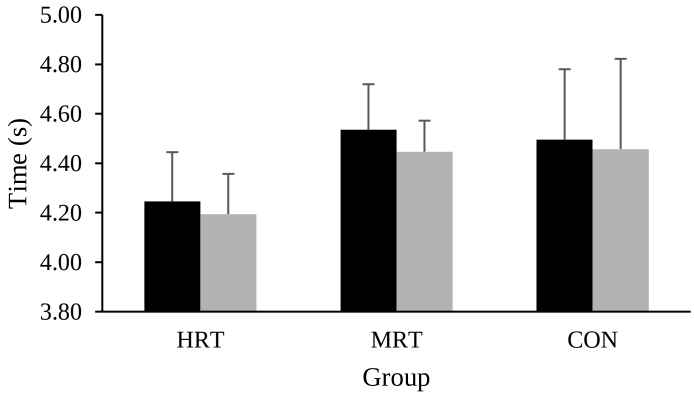


Figure 3: Changes in (A) 10 m, (B) 20 m and (C) 30 m sprint times pre- (black) and post-six-week intervention; HRT, high-intensity resistance training group; MRT, moderate-intensity resistance training group; CON, control group

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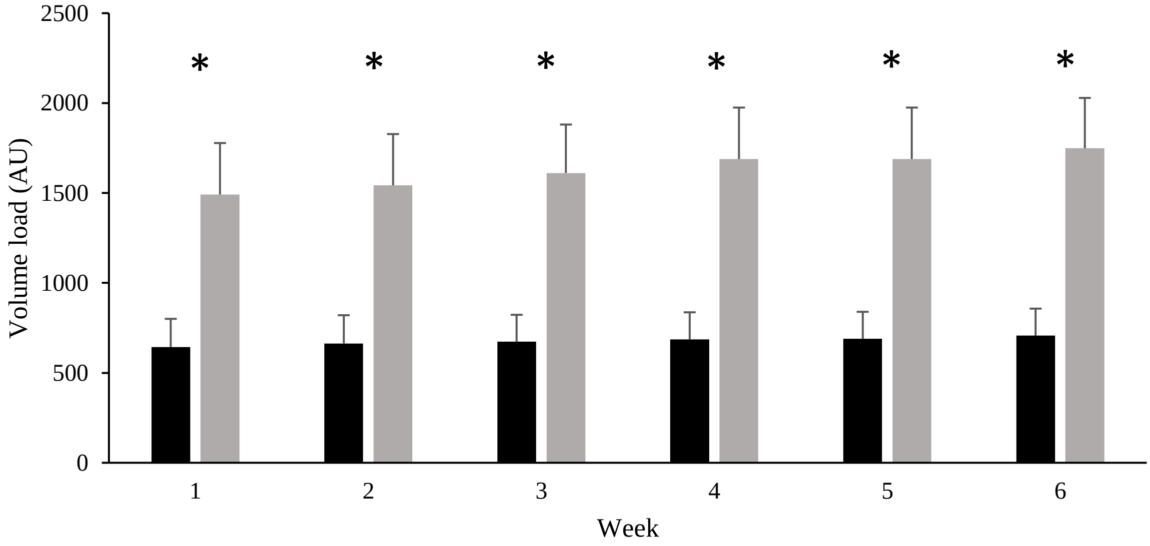

Figure 4: Weekly resistance training volume load completed by high-intensity resistance training group (black bars) and moderate-intensity resistance training group (grey bars). * significant difference between groups.

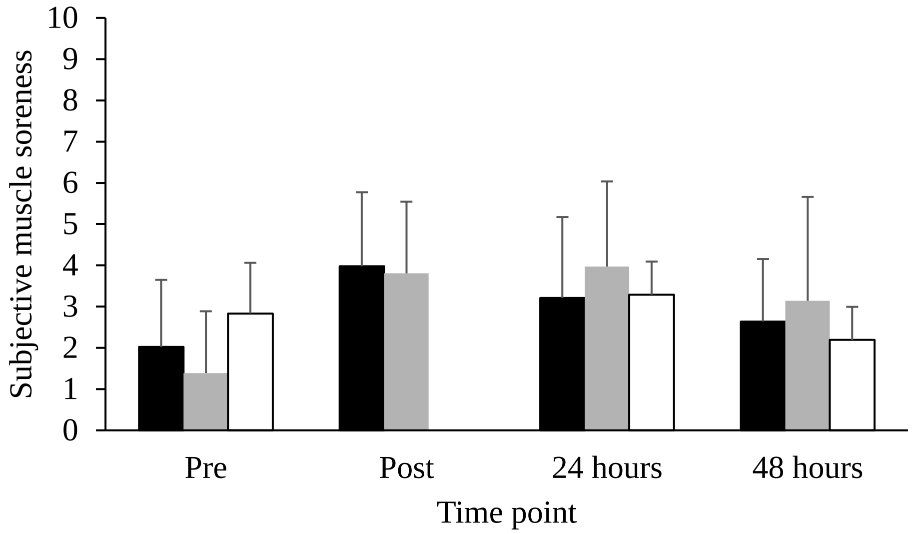

Figure 5: Time course of subjective lower-limb muscle soreness from prior to, immediately after, 24 hours after and 48 hours after each RT session. Black bars: High-intensity resistance training group (HRT); grey bars: moderate-intensity resistance training group (MRT); white bars: control group (CON).

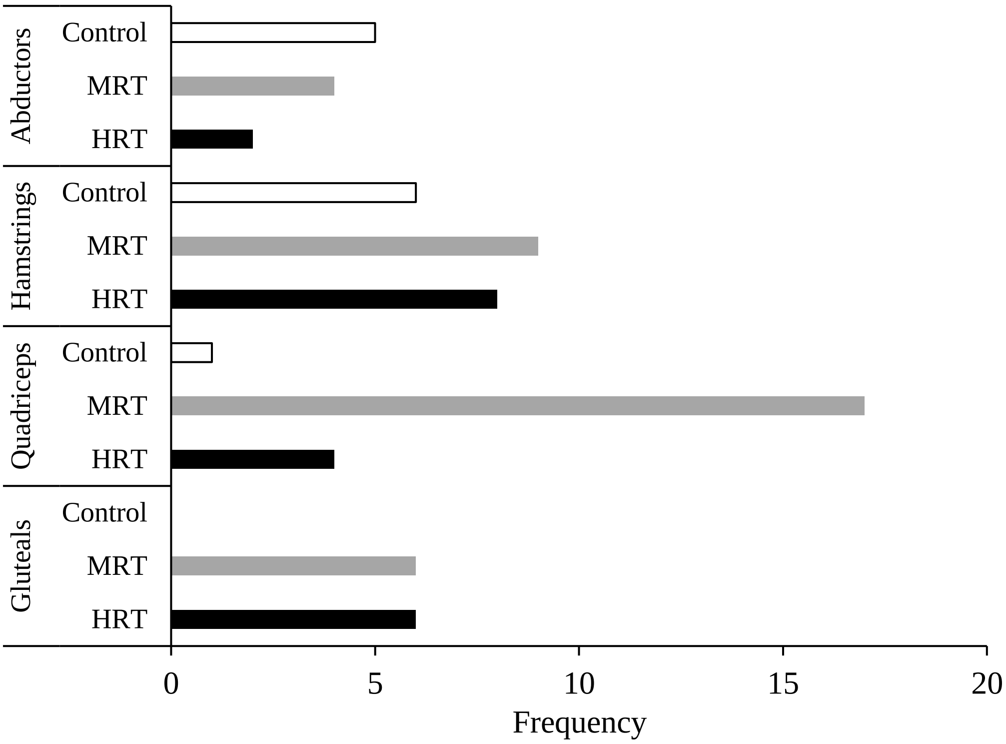

Figure 6: The frequency of muscle soreness location in the 24- and 48 hours following resistance training sessions.