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

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# 1 Abstract

2 The aims of this study were to investigate the impact of high-intensity, low-volume (HRT) vs. 3 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) 4 between groups in male academy soccer players (ASP). Twenty-two ASP (age: 18±1 years) 5 were assigned to either HRT (n=8), MRT (n=7) or CON (n=7). HRT completed 2 sets of 4 6 repetitions parallel back squat (PBS) repetitions at 90% 1RM, while MRT performed 3 sets of 7 8 8 repetitions PBS repetitions at 80% 1RM, both once a week for six-weeks in-season, alongside 9 regular soccer training. All groups completed the following pre- and post-training assessments: 10 3RM PBS; bilateral vertical and horizontal countermovement jumps (CMJ); squat jump (SJ); 11 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 12 (p=0.001), CMJ height (p=0.008) following training. There was a greater increase in PBS 3RM 13 relative to body mass following HRT than MRT and CON (p=0.001) and horizontal CMJ 14 distance improved in HRT but not in MRT or CON (p=0.011). There was no change in 10m, 15 20m or 30m sprint performance in any group. HRT volume was 58±15% lower than that of 16 MRT (p < 0.001) and DOMS measured throughout training did not differ between groups 17 (p=0.487). These findings suggest that one HRT session a week may be an efficient method 18 19 for improving strength and power in ASP in-season with minimal DOMS.

# 20 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  $81 \pm 18$  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 31 specific actions through a variety of training methods, of which resistance training (RT) is a 32 33 central component (21). Further, men's academy S&C coaches in the UK incorporate  $2 \pm 1$ S&C sessions per week, lasting  $45 \pm 14$  minutes (22). Conclusions from a youth RT meta-34 analysis suggest that the most effective training frequency to develop strength and power in 35 youth athletes is 2-3 sessions a week, while a single session may maintain established strength 36 levels (18). However, a single RT session per week can be sufficient to improve strength and 37 38 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 39 limited time is one of the main reasons given by S&C coaches for not incorporating RT into 40 their players' programmes. Thus, the inclusion of just one RT session per week may be 41 perceived as being more practically feasible for some practitioners. 42

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

49 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 50 the implementation of RT programmes during the competitive period should be feasible. 51 52 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 53 as hypertrophy/strength-endurance training (>6 repetitions at moderate-intensity) rather than 54 training to primarily improve strength (1 to 6 repetitions at high-intensity) (13, 17). Further, 55 the two main limiting factors reported by coaches for incorporating RT into soccer training are 56 57 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 58 session and the degree of DOMS experienced by the athlete, limiting these factors may help 59 60 maximise performance gains with minimal impact on time to complete soccer-specific training, while also mitigating DOMS. 61

62 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 63 squatting patterns were the most common movement prescribed by soccer academy S&C 64 65 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 66 training studies have implemented the half-squat, characterised by  $(80 - 100^{\circ} \text{ knee flexion})$ . 67 This is potentially due to participants having inadequate technique, and concerns regarding 68 lack of mobility and injury (9), or the belief that it is a more sport-specific range of motion 69 (32). However, full-  $(135 - 140^{\circ} \text{ knee flexion})$  and parallel-  $(110 - 120^{\circ} \text{ knee flexion})$  squats 70 have been shown to improve vertical jump, acceleration, and load-velocity characteristics more 71 so than half- and quarter-squats (2, 15, 31). 72

73 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 74 commonly utilised in soccer (22), using parallel squat training, on changes in strength, power 75 76 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 77 benefits would be similar between HRT and MRT, but that HRT would experience less DOMS 78 79 due to a lower training volume (making training session duration shorter), thus being a more effective training method. 80

# 81 METHODS

## 82 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 sixweek 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.

## 89 Subjects

To be eligible to take part, participants had to be young, healthy men, part of a regular soccertraining 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

96 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  $\times$  time interaction) effect 97 size  $(\eta_p^2 = 0.12; \alpha: 0.05;$  power: 0.80). Fifty-one soccer players volunteered to participate in the 98 study and provided written consent prior to start of the intervention. Ten players withdrew due 99 to injury sustained during soccer training/match-play (not as a consequence of the study) and 100 a further 20 could not complete the post-training assessments due to the COVID-19 pandemic. 101 A total of 22 participants completed the study (age = 16 to 19 years; height =  $178.5 \pm 6.5$  cm; 102 body mass =  $71.4 \pm 7.4$  kg) and included one goalkeeper, six defenders, six midfielders and 103 104 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) 105 106 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 107 only control group (CON: n = 7). Soccer training for all groups included four pitch training 108 sessions per week, ranging from 60 to 120 minutes, plus one competitive match. Groups were 109 matched according to their baseline 3RM, age, height and body mass. The groups in the final 110 111 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). 112 Final groups (Table 1). All participants provided written informed consent prior to taking part 113 in the study, which was approved by the Liverpool John Moores University Research Ethics 114 Committee and complied with the Declaration of Helsinki. 115

116

#### \*\*\*\*\*Table one\*\*\*\*

## 117 *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

120 countermovement jumps (CMJ), and 3RM back squat. Both HRT and MRT completed a six-121 week in-season RT programme alongside regular soccer training, with one session a week on 122 match day minus two (two days prior to a competitive fixture). HRT completed two sets of 123 four repetitions of parallel back squat at 90% 1RM (estimated from 3RM), while the MRT 124 group performed three sets of eight repetitions of parallel back squat at 80% 1RM. CON 125 performed their regular soccer training for the six-week period.

## 126 *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.

### 131 *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).

136 
$$Maturity \, Offset = -29.769 + 0.0003007 \cdot$$

137 Leg Length and Sitting Height interaction -0.01177.

138 Age and Leg Length interaction  $x \ 0.01639 \cdot Age$  and Sitting Height interaction +

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

143 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 144 effect of arm swing on performance. Participants were instructed to land on the balls of their 145 feet followed by three small bounces on the indoor gym floor. This was done to control jump 146 and landing positions, as jump height was calculated indirectly via flight time (Optojump, 147 Microgate, Bolzano, Italy). This method has been shown to have excellent reliability (intra-148 class correlation (ICC) = 0.982 - 0.989) and low coefficients of variation (CV = 2.8%) in a 149 similar cohort (11). Horizontal CMJ testing was performed on an outdoor artificial grass 150 151 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 152 landing with the measurement taken from the heel of the foot nearest the start line. For each of 153 154 the three jump types, if the third attempt was the best, participants were given additional 155 attempts until results no longer increased. The peak value was used in subsequent analysis.

156 All participants completed a 15-minute standardised warm-up prior to sprint testing. The warmup consisted of light jogging and running drills (5 minutes), dynamic bodyweight movements 157 (split squats, lunges, glute bridge, hamstring walk outs; 2 sets of 6 repetition each), submaximal 158 159 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 160 with no countermovement behind the start line. Timing gates (TCi System, Brower, Salt Lake 161 City, USA) were placed 1 m, 11 m, 21 m and 31 m from the start line. Participants were 162 163 instructed to sprint beyond the final gate to ensure no slowing down prior to completion. There 164 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 165 166 recorded in three participants, so sample size for this assessment was HRT, n=6; MRT, n=7; 167 CON, n=6. These sprint distances have previously been reported to have good reliability (10

168 m, ICC = 0.78 (95% confidence intervals: 0.57 - 0.89); 20 m, ICC = 0.78 (0.85 - 0.97)) and 169 low coefficients of variation (10 m = 2.4%; 20 m = 1.4%) in academy soccer players (7).

170 *Testing Day Two* 

Maximal lower limb strength was assessed via 3RM parallel back squat. Prior to the test, 171 participants performed a standardised warm up of 10 repetitions with an unloaded bar, five 172 repetitions with 50% body mass and three repetitions with 75% body mass with loads rounded 173 to the nearest 0.25 kg. All squats were performed to parallel, i.e. where the tops of the thighs 174 were horizontal to the ground (110 -120° knee flexion), with each repetition assessed visually 175 by the investigator. The load lifted was increased following each successful attempt based on 176 the difficulty it was completed with. An attempt was deemed a failure if the participant did not 177 178 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 179 of lower body strength irrespective of RT experience and age (12). Testing was visually 180 monitored by the researcher and each participant rested three to five minutes after each attempt 181 (13). 182

### **183** *Training Programme*

To familiarise all participants with the parallel back squat and ensure that all could complete 184 185 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 186 study until their technique was considered to be appropriate by a National Association for 187 Strength and Conditioning (NSCA)-accredited S&C coach. All RT sessions and testing were 188 led by the same NSCA-accredited S&C coach with a relevant Masters degree and >10 years' 189 coaching experience (SM). Following baseline testing, participants in the training groups 190 completed a once-weekly RT programme, implemented concurrently with regular soccer 191

192 training on match day minus two. Each squat training session comprised a bodyweight warmup (10 repetitions of squats, lunges and glute bridges), barbell warm-up sets of 10 repetitions 193 at 20 kg, 8 repetitions at 50% and 5 repetitions at 70% estimated 1RM, as described above, 194 195 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 196 were prescribed by using the Epley equation  $(1RM = ([0.033 \times Repetitions] \times Load) + Load)$  to 197 198 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 199 200 increased when the participant could safely and correctly complete the prescribed load.

## 201 Monitoring DOMS and training load

202 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 203 session using a visual analogue scale (VAS). The scale ranged from 0 cm, referring to no 204 soreness, up to 10 cm, which would indicate extreme muscle soreness (1). At the 24 hour and 205 48-hour post training time points, participants reported their lower body muscle soreness via a 206 207 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 208 volume load was calculated by multiplying repetitions by sets and external load lifted. 209

## 210 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  $\pm$  standard deviation (SD) and statistical significance was set at p < 0.05.

# 223 **RESULTS**

## 224 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- ( $75.1 \pm 8.4$  kg) to post-intervention ( $77.4 \pm 9.5$  kg, p = 0.029) compared to HRT (pre:  $68.2 \pm 6.5$  kg, post:  $68.7 \pm 6.4$  kg, p = 0.049) but not CON (pre:  $71.6 \pm 6.4$  kg, post:  $71.1 \pm 6.0$  kg, p = 0.216).

### 231 Height

There was a main effect of time ( $F_{1, 19} = 17.52$ , p = 0.001), HRT increased from  $174.8 \pm 5.8$ 

233 cm to 175.4  $\pm$  6.0 cm, MRT from 182.5  $\pm$  6.9 cm to 183.3  $\pm$  6.7 cm and CON from 178.8  $\pm$  5.1

to  $179.8 \pm 5.1$  cm. There was no main effect of group ( $F_{2, 19} = 3.22$ , p = 0.063) and no interaction

235 between time and group ( $F_{2, 19} = 0.31$ , p = 0.735).

236 Absolute Strength

237 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  $(F_{1,19} = 18.02, \eta_p^2)$ 238 = 0.655, p < 0.001). Post-hoc paired t-tests with Bonferroni correction demonstrated that 239 absolute back squat strength increased in HRT ( $t_7 = -7.77$ , p < 0.001, d = 0.80) and MRT ( $t_6 =$ 240 -6.49, p = 0.001, d = 1.35) but not in CON ( $t_6 = -1.27$ , p = 0.253, Fig 1a). Pre-intervention 241 testing established the smallest worthwhile change for estimated 1RM to be 3.39 kg. A one-242 way between groups ANOVA (p < 0.001) revealed that the % change in absolute strength was 243 greater in HRT (+17.1  $\pm$ 7.5%, p = 0.025) and MRT (+29.1  $\pm$  15.8%, p < 0.001) compared to 244 245 CON (+1.7  $\pm$  3.4%) but did not differ between HRT and MRT (p = 0.100).

## 246 *Relative Strength*

247 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 =248 0.001). Post-hoc paired t-tests with Bonferroni correction demonstrated that relative back squat 249 strength increased in HRT ( $t_7 = -6.11$ , p < 0.001, d = 1.31) and MRT ( $t_6 = -6.64$ , p = 0.001, d250 = 1.11) but not CON ( $t_6$  = -1.53, p = 0.176, Fig 1b). Pre-intervention testing established the 251 252 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) 253  $\pm$  8.1%, p = 0.035) and MRT (+25.2  $\pm$  14.1%, p .0.001) compared to CON (+2.4  $\pm$  3.9%) but 254 255 did not differ between HRT and MRT (p = 0.255).

256

#### \*\*\*\*\*Figure one\*\*\*\*\*

## 257 Squat jump (SJ) height

258 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) 259 but there was interaction between time and group ( $F_{2, 19} = 11.33$ ,  $\eta_p^2 = 0.544$ , p = 0.001, Fig 260 2a). Post-hoc paired t-tests with Bonferroni correction demonstrated that SJ height increased 261 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 262 in CON ( $t_6 = 2.55$ , p = 0.044, d = 0.44, Fig 2a). Pre-intervention testing established the smallest 263 worthwhile change to be 0.8 cm. A one-way between groups ANOVA (p < 0.001) revealed 264 that the % change in SJ height was greater in HRT (+6.1 ± 6.8%, p = 0.006) and MRT (+10.8 265 ± 7.2%, p < 0.001) compared to CON (-6.5 ± 6.6%) but did not differ between HRT and MRT 266 (p = 0.621).

## 267 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 268 time ( $F_{1, 19} = 6.42$ , p = 0.020) and an interaction between time and group ( $F_{2, 19} = 6.33$ ,  $\eta_p^2 =$ 269 270 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 = -4.23, q = -271 0.70) but not in CON ( $t_6 = 1.02$ , p = 0.346, Fig 2b). Pre-intervention testing established the 272 smallest worthwhile change to be 0.9 cm. A one-way between groups ANOVA (p = 0.010) 273 revealed that the % change in CMJ height was greater in HRT ( $+8.8 \pm 8.2\%$ , p = 0.027) and 274 275 MRT (+10.0  $\pm$  6.4%, p = 0.018) compared to CON (-4.0  $\pm$  10.4%) but did not differ between HRT and MRT (p = 1.000). 276

## 277 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 ( $F_{2, 19} = 6.02$ ,  $\eta_p^2 = 0.415$ , 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  $\pm$  5.3%, *p* = 0.231) compared to CON (+1.9  $\pm$  3.9%). There was no difference between MRT and HRT (+5.6  $\pm$ 7.1%, *p* = 0.231) or MRT and CON (*p* = 0.744)

## 288 10 m Sprint time

287

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). Preintervention testing established the smallest worthwhile change to be 0.02 s.

# 292 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). Preintervention 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). Preintervention testing established the smallest worthwhile change to be 0.05 s.

# 301 *Training volume*

302 There was a main effect for group ( $F_{1, 13} = 76.35$ , p < 0.001), time ( $F_{5, 65} = 55.86$ , p < 0.001) 303 and an interaction between group and time ( $F_{5, 65} = 20.80$ , p < 0.001). HRT started with a volume of  $633 \pm 136$  kg, increasing to  $700 \pm 128$  kg, whereas MRT started with initial volume of  $1491 \pm 287$  kg, increasing to  $1749 \pm 280$  kg by week six (Fig 4).

306

\*\*\*\*\*Figure four\*\*\*\*\*

307 *DOMS* 

Regarding overall lower-limb DOMS, there was no main effect for group ( $F_{2,110} = 0.24$ , p =308 0.784) but there was for time ( $F_{2,220} = 34.62$ , p < 0.001) and a significant interaction between 309 group and time ( $F_{2,220} = 10.71$ , p < 0.001, Fig 5). MRT had the greatest increase from pre- to 310 24 hours post RT (+2.4 cm; p = 0.38) compared to HRT (+1.6 cm). DOMS decreased from 24 311 hours to 48 hours to a similar extent in HRT (-0.5 cm; p = 0.231) MRT (-1.0 cm) and (CON -312 1.05 cm; Fig 5). When comparing the locations of muscle soreness, there were similar 313 frequencies recorded between training groups for gluteus, hamstrings and hip adductors. 314 However, MRT reported more quadriceps soreness counts than HRT did (Fig 6). 315

- 316 \*\*\*\*\*Figure five\*\*\*\*\*
- 317

\*\*\*\*\*Figure six\*\*\*\*

## 318 **DISCUSSION**

The aim of this study was to compare the impact of six weeks' in-season high-intensity (lowvolume) 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)).

330 Increasing strength, particularly strength relative to body mass, can have a beneficial impact 331 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 332 in-season (34). This is a key finding for academy S&C coaches, who may be restricted to a 333 334 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 335 on the results presented here, it is possible to increase strength in academy aged soccer players 336 with a single RT training session per week. 337

Lower-body power is regularly assessed using jump assessments, with 95% of academy S&C 338 coaches using them in practice (23). In the current study, both HRT and MRT resulted in 339 improvements in SJ (Fig 2), which is in line with previous research in soccer players aged 15-340 341 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 342 in academy soccer players. Chelly, et al. (4) showed no changes following an eight-week high-343 344 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 345 inconsistency between results may be due to Hammami, et al. (14) programming a greater 346 347 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 348 by velocity, the use of the parallel squat in the present study may explain how both HRT and 349

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 353 354 in a single plane. Horizontal orientated jump assessments may be more appropriate to use in 355 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 356 under 18 year-old men's academy matches (28). Furthermore, horizontal jumps can be used to 357 358 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 359 HRT and MRT increased absolute and relative strength, and change in strength correlates with 360 improvement in acceleration performance (36). This may be due to the technical element of 361 sprint performance, as horizontal jump performance predicts only 66% of 10 and 20 m 362 363 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 364 of the greater power production into faster sprint performance (26). Alternatively, it is possible 365 366 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 367 estimated minimal sample required (n = 21), prevented us from detecting a group  $\times$  time 368 interaction. In fact, post-hoc power calculations revealed a statistical power of ~50% for the 369 370 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 371 statistically powered to detect group × time interactions regarding changes in strength and 372 (vertical and horizontal) CMJ performance. 373

374 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 375 training volumes coaches were prescribing in-season, as shown by the greater DOMS scores 376 377 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 378 academy soccer players. An unexpected finding were the specific sites where soccer players 379 380 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 381 382 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 383 note that HRT achieved these with 58% less volume load. When volume load is matched, 384 385 Uchida, et al. (38) showed no differences in DOMS or plasma creatine kinase following 386 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 387 388 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 389 390 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). 391

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.

## 403 PRACTICAL APPLICATIONS

To conclude, six weeks' low-volume, high-intensity (90% 1RM) RT, and high volume, 404 moderate-intensity (80% 1RM) RT both led to improvements in lower-limb strength and power 405 406 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-407 intensity group (Fig 4), and similar muscle soreness to soccer training alone in the subsequent 408 409 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-410 season than the most common training prescription currently used by coaches in soccer (i.e. 411 moderate-intensity, high-volume resistance training). Future studies should investigate the 412 medium- to long-term effect of high-intensity, low-volume resistance training on the physical 413 414 development of youth (men and women) soccer players.

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## 417 **Data availability statement**

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

## 420 Disclosure statement

- 421 The authors report no conflicts of interest and the results of the present study do not constitute
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Table 1: Participant characteristics

	HRT (n=8)	MRT (n=7)	Control (n=7)
Chronological age (years)	$18 \pm 1$	$18 \pm 1$	19 ± 1
Body mass (kg)	$68.2\pm6.5$	$75.1\pm8.4$	$71.6\pm6.4$
Height (cm)	$174.8\pm5.8$	$182.5\pm6.9$	$178.8\pm5.13$
Maturity offset	$2.76\pm0.76$	$2.82\pm0.95$	$3.87 \pm 3.93*$
Estimated 1RM (kg)	$89.24 \pm 18.72$	$78.50 \pm 16.09$	$99.35 \pm 7.53$
1RM relative to body mass	$1.3\pm0.2$	$1.1\pm0.2$	$1.4 \pm 0.1$

1RM, single repetition maximum.

\*higher than HRT and MRT

541



**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.



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



**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: Highintensity 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.