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ORIGINAL ARTICLE

The effect of concurrent training organisation in youth elite soccer players

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Abstract
Purpose This study compared the adaptive responses to two concurrent training programmes frequently used in professional soccer.
Methods Fifteen youth soccer players (17.3 ± 1.6 years, 1.82 ± 0.06 m, 77.0 ± 7.3 kg; VO_2 peak, 62.0 ± 4.7 ml^{-1} kg^{-1} min^{-1}) who compete in the English Premier League volunteered for this study. In addition to completing their habitual training practices, the participants were asked to alter the organisation concurrent training by performing strength (*S*) training either prior to ($S + E$, $n = 8$) or after ($E + S$, $n = 7$) soccer-specific endurance training (*E*) 2d wk^{-1} for 5 wk^{-1}.
Results With the exception of 30 m sprint, IMVC PF, quadriceps strength (60°/s^{CON}, 180°/s^{CON}, 120°/s^{ECC}) pooled data revealed training effects across all other performances measures ($P < 0.05$). Whilst ANCOVA indicated no significant interaction effects for training condition, the difference between the means divided by the pooled standard deviation demonstrated large effect sizes in the E + S condition for in HBS 1-RM [$S + E$ vs $E + S$; −0.54 (9.6 %) vs −1.79 (19.6 %)], AoP-M [−0.72 (7.9 %) vs −1.76 (14.4 %)], SJ [−0.56, (4.4 %), vs −1.08, (8.1 %)], IMVC-LR; [−0.50, (20.3 %) vs −1.05 (27.3 %)], isokinetic hamstring strength 60°/s ^{CON} [−0.64, (12.2 %) vs −0.95 (19.2 %)], 120°/s^{ECC} [−0.78 (27.9 %) vs −1.55 (23.3 %)] and isokinetic quadriceps strength 180°/s ^{CON} [−0.23 (2.5 %) vs −1.52 (13.2 %)].
Conclusion Results suggest the organisation of concurrent training, recovery time allocated between training bouts and the availability nutrition may be able to modulate small but clinically significant changes in physical performance parameters associated with match-play. This may have practical implications for practitioners who prescribe same day concurrent training protocols.

Keywords Concurrent training · Strength training · Soccer · Muscle architecture

Abbreviations

$S + E$	Strength-endurance scenario
$E + S$	Endurance-strength scenario
HBS 1RM	Half back squat 1-RM
IMVC PF	Isometric MVC peak force
IMVC LR	Isometric MVC loading rate
Quad Con60	Concentric quadriceps (60°/s)
Quad Con180	Concentric quadriceps (180°/s)
Quad Ecc120	Eccentric quadriceps (120°/s)
Ham Con60	Concentric hamstrings (60°/s)
Ham Con180	Concentric hamstrings (180°/s)
Ham Ecc120	Eccentric hamstrings (120°/s)
SJ	Squat Jump
CMJ	Countermovement jump
MT-D	Muscle thickness (distal)
MT-M	Muscle thickness (mid)

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MT-P	Muscle thickness (proximal)
AoP-M	Angle of pennation (Mid)
FL-M	Fascicule length (Mid)

Introduction

Elite athletes often combine maximal muscle strength and endurance training within the same training cycle. This training arrangement has been defined as 'concurrent training' (Fyfe et al. 2014). Previously, it has been documented that concurrent training can result in compromised muscle strength and (or) power capacity (for review see; Wilson et al. 2012). This 'blunted' response in strength-related adaptation has been referred to as the 'interference phenomenon' (Hickson 1980). Over the past three decades, authors have proposed a variety of hypothesis to explain this phenomenon. These include; an inability to adapt as a consequence of contrasting training intensities (Docherty and Sporer 2000), an incompatible hormonal (Bell et al. 2000) and (or) molecular signalling environment (Atherton et al. 2005) the 'sequence' or 'order' of training (Chtaha et al. 2008), the recovery time between training bouts (Craig et al. 1991) and the frequency of aerobic training (Wilson et al. 2012) resulting in 'overtraining' (Dudley and Fleck 1987). These explanations can be 'broadly grouped' into two hypothesis; (1) interference is caused by acute peripheral fatigue and in the inability to effectively train at appropriate intensities to achieve the desired outcome (i.e., acute interference) and (2) interference is a consequence of molecular and (or) biological events blocking strength-related adaptation (i.e., chronic interference). Both of the above categories in part, can be influenced by the way the training stimulus is organised or arranged across the training week.

The challenge of organising training for team sport athletes who require diverse fitness components [e.g., aerobic capacity, repeated sprint ability, maximal muscle strength and (or) explosive power] is great, particularly for the elite soccer player (Bangsbo et al. 2006). To be competitive, these athletes need high levels of aerobic and anaerobic capacity and the ability to be powerful in match-specific movements (e.g., jumping, tackling and accelerating) (Mhor et al. 2003; Wisloff et al. 2004). Furthermore, available training time for soccer players is often limited owing to the competitive schedule where players play in excess of 40 games per season, with these matches often performed as frequently as 2–3 times per week during intense fixture period (Morgans et al. 2014). As such, these athletes routinely engage in concurrent training models where aerobic fitness is developed using high-intensity sport-specific conditioning games and drills (Little and Williams 2006) whilst maximal muscle strength and explosive power is developed and maintained using high-load low-repetition strength training regimes (Wisloff et al. 1998; Hoff et al. 2004).

In applied sporting environments, it is not always possible to isolate strength and endurance training on separate days. This is largely due to the competition schedule, restricted training time and other contextual barriers unique to this environment (e.g., large numbers of athletes, the availability of appropriate strength training facilities and (or) equipment (unpublished observations). As a result, the habitual training practices of English professional soccer players can involve unsystematic training arrangements and (or) sessions performed within close proximity. Understanding the physiological responses to the concurrent training practices typically used in applied environments may be important. This may lead to a better understanding of how to minimise the interference phenomenon and prescribe more effective training stimuli in this environment.

Relatively few training studies (Bell et al. 1988; Collins et al. 1993; Gravelle and Blessing 2000; Chtara et al. 2005; Chtara et al. 2008; Small et al. 2009; McGawley and Andersson 2013) have investigated the effect of altering the order of same day concurrent training. Collectively, these studies have reported small but similar improvements in leg strength in both training conditions and concluded negligible effects of altering the concurrent training sequence. However, the majority of the above studies have used 'untrained' participants. Although, one study used elite Swedish soccer players to investigate the effect of performing concurrent 'power-training' and 'high intensity interval training' in opposing orders (McGawley and Andersson 2013). This study also found minimal effects of altering the concurrent training sequence. However, the training practices employed in this study were not indicative of the training practices typically seen within English premier league clubs (for example, these teams do not routinely combine two 30 min football and strength training sessions together or train in the evening ~19:00 h). To the authors knowledge, no studies have investigated the effect of concurrent training sequence in English soccer players. As a result, little is known about habitual concurrent training practices within English academy soccer clubs or the effect of these training interventions. As a result, additional research is required to understand the effects of the concurrent training practices typically seen within this unique environment. This may offer a starting point from which future studies could be designed to improve the effectiveness of concurrent training programmes in this environment.

With this in mind, the aim of the present study was to observe and compare the training responses to two concurrent training scenarios previously observed at a professional football club in England (Enright 2014). Given that long-term training adaptations can be considered the cumulative

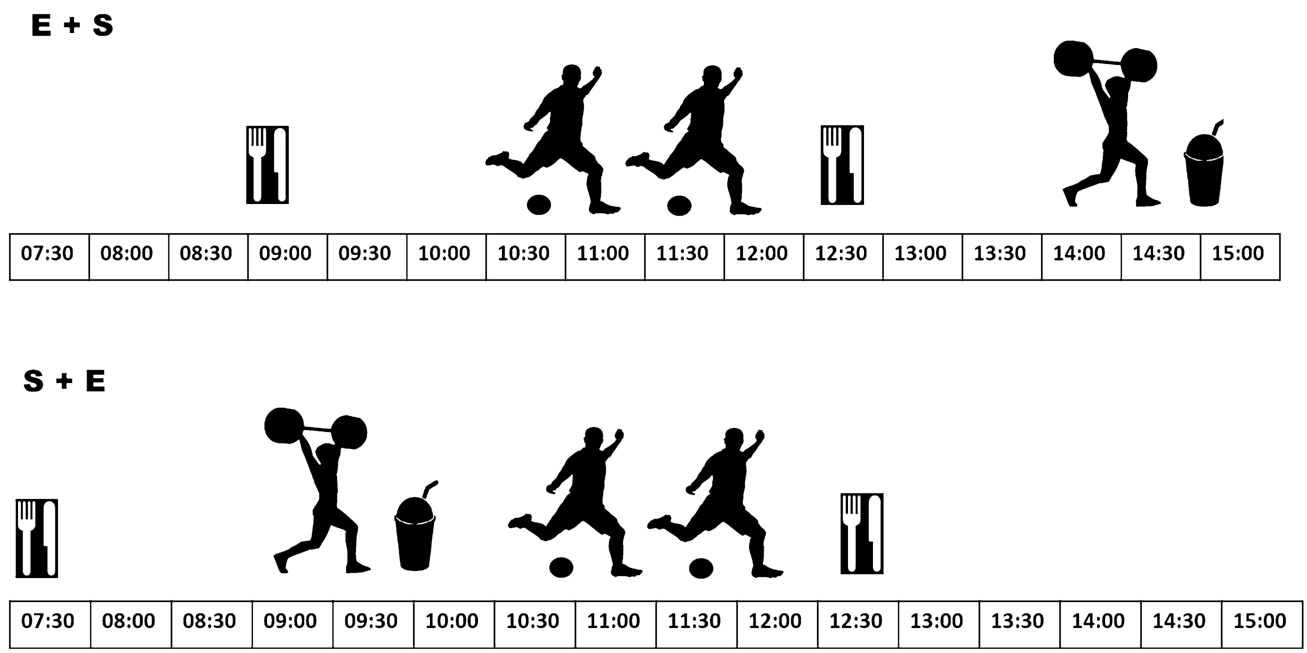


Fig. 1 Schematic depicting the two exercise sequences employed. *S* + *E* strength-endurance sequence, *E* + *S* endurance-strength sequence, *Meal* breakfast/lunch, *S* Strength training, *E* Endurance training, ↓ 25 g whey protein. Note that whilst the pattern of energy delivery was different between trials, the total energy availability over the study period was matched

effects of acute alterations in physiological responses to training stimuli, it was hypothesised that the organisation of concurrent training could mediate training adaptations. To this end, we employed a design whereby two groups of athletes performed their habitual training practices for 5 weeks. Here, we modified the organisation of concurrent strength and football training on two of training days each week in line with what was typically observed in this environment (Fig. 1). Group 1 performed strength (S) immediately followed by soccer-specific endurance training (E) (both within a 3–4 h morning period) ($S + E$) (~08:45 and 10:30 h, respectively), whereas, Group 2 performed the same soccer-specific endurance training in the morning (~10:30 h) followed by strength training in the early afternoon period ($E + S$) (~14:00 h). Before and after the observation period training responses were monitored using a range of muscle strength, power and morphology indices.

Methods

Participants

Twenty professional male soccer players (academy level) from an English FA Premier League Club volunteered to participate in this study (mean ± SD: age, 17 ± 2 years; stature, 1.82 ± 0.06 m; body mass, 77.0 ± 7.3 kg; VO_2 peak, 62.0 ± 4.7 ml^{-1} kg^{-1} min^{-1}). All participants had a minimum of 2 years strength training history and were familiar with the present strength training protocols. After receiving oral and written information concerning any possible risks associated with the training and testing protocols, all participants gave their written informed consent to participate in the study. The study conformed to the code of ethics of the World Medical Association and was approved by the Ethics Committee of Liverpool John Moores University.

Overview of experimental design

The participants completed 4 football training sessions, 2 strength training sessions and 1 competitive game per week for 5 weeks. On concurrent training days, the players performed strength training before ($S + E$) or after ($E + S$) soccer-specific endurance training. During the week before and after the 5-week training block, participants were assessed for measures of muscle strength, power and muscle morphology.

The adherence to training in this study was ≥90 %; this equated to ≥18 football training sessions, ≥9 strength training sessions and ≥4.5 games. Five players did not adhere to these criteria. This was due to unavoidable contact injuries ($n = 2$) and a varied training schedule ($n = 3$) associated with playing for the clubs' under-21 team, and as such, data are presented hereafter for the 15 players who had 90 % adherence to all aspects of training and competition ($E + S$, $n = 7$; $S + E$, $n = 8$).

Table 1 Summary of the training load completed by each experimental group (statistical analysis revealed no differences between groups)

Week	$S + E$					$E + S$				
	No. of sessions	Total duration (mins)	Average minutes >85 % HR max	Strength volume load	RPE load (RPE × Min)	No. of sessions	Total duration (mins)	Average minutes >85 % HR max	Strength volume load	RPE load (RPE × min)
Week 1	6.0	490	00:32:20	13,251 ± 236	2400.0	6.0	490	00:30:53	12,217.5 ± 1047	2344.0
Week 2	6.0	633	00:28:56	15,758 ± 8626	3504.9	6.0	633	00:35:02	12,228 ± 107	3349.0
Week 3	6.0	532	00:28:52	9330 ± 4823	2704.3	6.0	532	00:30:35	10,035 ± 4723	2650.0
Week 4	6.0	487	00:23:36	13,988 ± 4947	2465.4	6.0	487	00:24:55	14,430 ± 3360	2290.0
Week 5	6.0	554	00:39:00	14,890 ± 4239	3041.9	6.0	554	00:47:59	12,795 ± 4698	2980.0
M ± SD	6.0	539.3 ± 59.6	00:30:33 ± 00:05:40	13,443 ± 2485	2823 ± 456	6.0	539.3 ± 59.6	00:33:53 ± 00:08:40	12,341 ± 1574	2722 ± 445
Total	30.0	2696.5	02:32:44	67,217	14116.5	30.0	2696.5	02:49:24	61,705	13613.0

Training interventions

The observation phase was carried out in the first 5 weeks of the competitive season (August/September). During each week, all participants completed two technical and tactical soccer practices, two soccer-specific endurance training sessions (*E*), two strength training sessions (*S*) and one competitive game. Participants completed concurrent '*E*' and '*S*' training on Mondays and Thursdays (deliberately scheduled to follow rest days of Sunday and Wednesday). On concurrent training days those participants allocated to the '$S + E$' group completed '*S*' training at 0845 h ± 15 min prior to '*E*' at 1030 h. Participant s in the '$E + S$' group, participated in the same '*E*' training session at 1030 h followed by '*S*' training at 1400 h ± 15 min. On concurrent training days, all participants completed the same football specific endurance-training session at 1030 h. An overview of the organisation of the $S + E$ and $E + S$ concurrent training scenarios is shown in Fig. 1.

Soccer-specific endurance training stimuli '*E*' consisted of a dynamic warm-up (~20 min), small-sided games (~25 min) and technical/tactical work (~50 min). For hydration purposes, regular intervals were also provided throughout each '*E*' training session. Small-sided games involved a 4 verses 4, possession format. Each game lasted 4 min and was performed at an intensity of ~85–95 % HR max. Between each game, 3 min of active recovery was allocated. Games were performed on a 37 × 27 m pitch (for more detail on this game format and reliability statistics please refer to (Little and Williams 2007). Following a 10-min rest interval, the players participated in additional technical and tactical training. Additional technical and tactical aspect of the training programme was designed and delivered by the team coach, and involved a variety of soccer-specific drills and exercises. The mean duration of the entire session '*E*' was 113 ± 21 min and players' average perceived exertion score using 'Borg's 1–10 rating of perceived exertion scale' (Siegl and Schultz 1984) was 7 ± 1.

The strength training programme consisted of 4 sets of 6 maximal repetitions (85 % of 1RM) of the following exercises: parallel back squat, dead-lift, stiff-leg dead-lift and front-lunge. Participants also completed 3 sets of 8 repetitions of the Nordic hamstring exercise. Before strength training the participants completed a 5-min dynamic warm-up followed by a 'barbell warm-up' (3 × 10 repetitions; 20 kg) using the same exercises used in the training intervention. An Accredited Strength-and-Conditioning Coach (ASCC) from the United Kingdom Strength-and-Conditioning Association (UKSCA) designed and supervised the strength training sessions (author 1). Training compliance and individual workout data (weight lifted, number of sets and repetitions completed), (for a more detailed view of the training load for each experimental

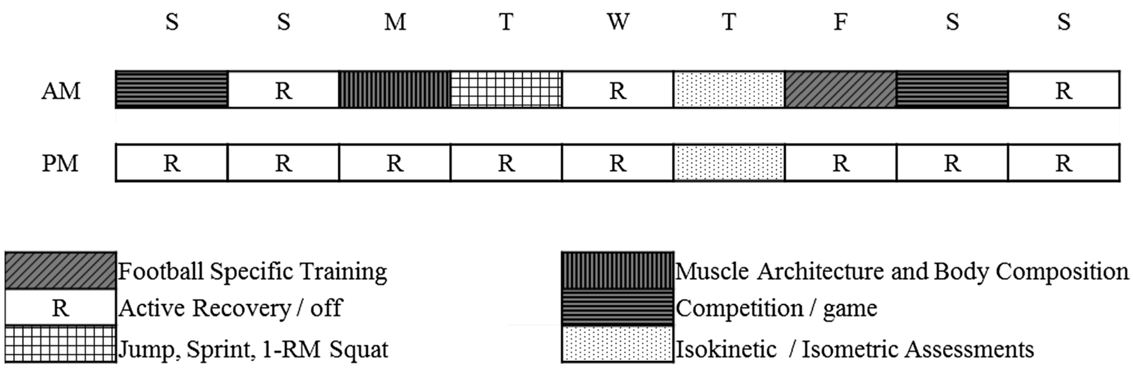


Fig. 2 The organisation of physiological testing before and after the intervention period

group refer to Table 1) was recorded for each participant for all sessions. During each strength training session the participants were instructed to increase the weight on the bar (in kilograms) so that they were lifting their maximum intensity during each set of repetitions. The mean duration of S was 40 ± 5 min and players' average perceived exertion score was 8 ± 1. Prior to the observation period, all athletes participated in a 'strength training familiarisation phase' which took place during the 'pre-season'. Using a linear periodisation technique, all athletes participated in 2 strength training session's wk^{-1} for 5 wk^{-1}. Strength training involved the same exercises as the observation period with the exception that players completed 3 sets of 8 repetitions (60–80 % of estimated 1RM). To reduce the likelihood of the familiarisation phase affecting our results participants completed alternating orders (i.e., $E + S$ or $S + E$) throughout the familiarisation period.

Dietary controls

On concurrent training days (Monday and Wednesday), a standardised breakfast was consumed at 0800 and 0900 h for S + E and E + S, respectively (~540 kcal: 100 g carbohydrate, 15 g protein and 7 g fat). Following observation a players also consumed similar nutrient intake at the 1230 h meal time (~1000 kcal 140 g carbohydrate, 60 g protein and 25 g fat). Finally, all players consumed a standardised recovery shake upon completion of strength training so as to ensure nutrient provision prior to E at 1030 h (~220 kcal: 25 g protein, 13 g carbohydrate, 0.5 g fat, Multipower, UK). In this way, all players were provided with comparable total energy content for the hours in which the players were physically present at the soccer club, though the timing of nutrient intake varied between groups. Nonetheless this design represented two scenarios, which occurred often within the club depending on the training schedule and as such we consider our approach to have high ecological validity.

Testing procedures

A battery of assessments designed to measure muscle strength [peak isokinetic force of the dominant quadriceps and hamstring muscle groups, maximal isometric voluntary contraction (MIVC) for the quadriceps and 1-repetition maximum (1-RM) for the half-back squat exercise, power (MIVC rate of force development, vertical jump height, the 10 and 30 m sprinting time] and muscle morphology were administered before and after the training intervention. Muscle morphology variables included muscle thickness and muscle architecture (fascicule angle of pennation and fascicule length) of the dominant thigh. Due to the nature of this study, testing physical assessments took place 1 week prior to and following the intervention period and was completed around the habitual training and competition practices at the club. The schedule of testing is described in Fig. 2 and was as follows; muscle architecture and body composition were measured 0900–1100 h on day 1 (Monday). On day 2 (Tuesday) following two consecutive days of rest vertical jump height, (0900 h) sprint speed (1000 h) and 1RM squat strength (1200 h) was measured, respectively. Following a recovery day, isometric and isokinetic leg strength were measured (testing day 3 Thursday). To minimise 'time-of-day effects' testing times were matched on each testing occasion.

All players had previously been familiarised with the performance tests (at the beginning of the pre-season period). Following familiarisation, a test re-test reliability investigation was carried out. Here, testing was performed 5–7 days apart and followed the same organisation as described in Fig. 2. Subsequent analysis revealed coefficient of variation (CV) from 1.6 to 12.4 % ($n = 17$). The highest variability occurred in eccentric hamstring contractions (isokinetic) whilst the lowest variability was observed in the half back squat exercise.

Muscle architecture and muscle thickness

Landmarks were placed at 30 % (proximal), 50 % (mid) and 70 % (distal) between the lateral femoral condyle and the greater trochanter (Kanehisa et al. 2003). Participants were then seated on the edge of a seat with hips and knees at right angles. Using a high-resolution B-mode ultra-sound scanner (12 MHz) (LOGIQ-e, Fairfield, Connecticut, U.S), images were taken at the designated landmark. To aid acoustic coupling during measurement, acoustic gel was placed over the probe head (40 mm linear-array transducer). Three sagittal images at each location were saved for analysis. Images were digitally analysed using built in 'LOGIQ-e software' to determine whole muscle thickness (WMT) (mid and distal locations), fascicle length (FL), and fascicle angle of pennation (AoP) (mid location). For information regarding the validity of the ultra-sound method to describe the muscle architecture characterises of human skeletal muscle please refer to Kellis et al. (2009).

Vertical jump height, sprinting speed and back squat strength

Following a recovery day, vertical jump height, 10 and 30 m sprint time and 1-repetition maximum in the half back squat exercise were assessed. Vertical jump height was measured using a jump mat (FLSelectronics, Cookstown, Northern Ireland). Participants were instructed to complete three maximal efforts in both the squat jump (SJ) and the countermovement jump (CMJ). Participants stood with feet shoulder width apart with their hands placed on their hips throughout each movement. A 3-min recovery period was allocated between each effort. The highest CMJ and SJ were recorded for analysis. Following a recovery period of 30 min, participants completed three maximal 30-m sprints on an outdoor grass surface. Between each sprint participants were allowed a 3-min recovery period (Ambrosoli and Cerretelli 1970). The fastest 10- and 30-m sprint time was recorded for analysis. The half back squat 1-RM was assessed using free weights and a squatting rack (Ivanko, San Pedro, California, U.S). Participants performed back squat specific warm-up repetitions of around 50, 70, 80 and 90 % of a previous 1-RM score. This was followed by a series of maximal repetitions, separated by 3- to 5-min rest periods. The maximum weight in kilograms lifted for a single repetition was recorded for analysis (knee angle of 90° between the participants' femur and tibia).

Isokinetic and isometric set-up

Measurements of isokinetic strength were assessed using an isokinetic dynamometer (Kin.com, Harrison Tennessee, U.S.). The initial setup involved aligning the rotational axis of the dynamometer with the posterior aspect of the participants' lateral femoral condoyle. At this position, the leaver arm length, dynamometer height and seat position was recorded and replicated. To minimise underestimation of knee extensor peak torque and overestimation of knee flexor peak torque, gravitational torque of the 'limb-lever system' was directly measured at 14° of knee flexion on each testing occasion (Morton et al. 2005).

Quadriceps maximal isometric voluntary contraction (MIVC), isometric loading rate (ILR)

To ensure each contraction was isometric, all participants were required to preload the force cell (~80 Newton's) in an upward direction for a period of 3 s prior to each repetition. Participants completed five maximal efforts with 2 min between contractions. Peak isometric force (N) and the repetition with the steepest gradient were recorded. The isometric loading rate (ILR) (rate of change) was calculated using the equation described by Woodard et al. (1999).

Isokinetic strength measurements

Isokinetic measurements involved bidirectional movements of the knee at 60, 120 and 180°/s and was performed throughout 90° to 10° of knee extension & flexion (0° is full extension). Slower angular velocity actions were performed before higher velocity tests to promote learning effects and reduce the risk of an injury. During each maximal repetition, the participants were instructed to hold the side of the seat whilst pushing as hard and as fast as they could. Standardised visual feedback using on screen graphs and verbal encouragement (Figoni and Morris 1984) was given throughout each test. To avoid any unwanted involvement from other muscle groups, stabilisation straps were placed across the trunk, pelvis and the engaged leg. Participants performed between three and five maximal efforts at each speed. A rest period of 30 s was allocated between consecutive bidirectional movements and 3 min between each angular velocity. The highest peak torque was recorded for analysis. Subsequent data was used to calculate the functional $\text{HAMSTRINGS}_{\text{ECCENTRIC}}$: $\text{QUADRICEPTS}_{\text{CONCENTRIC}}$ (H_{ECC}:Q_{CON}) at 60°/s and 180°/s (Iga et al. 2009).

Statistical analysis

The software package SPSS (Version 17.0 SPSS inc. Chicago, IL) was used for statistical analysis. A repeated measures two-way General Linear Model where the within factor was time (i.e., pre-training vs post-training) and between factor was group (i.e., $E + S$ vs $S + E$) was used to examine the effects of training sequence on changes in muscle strength, power and morphology. Where there

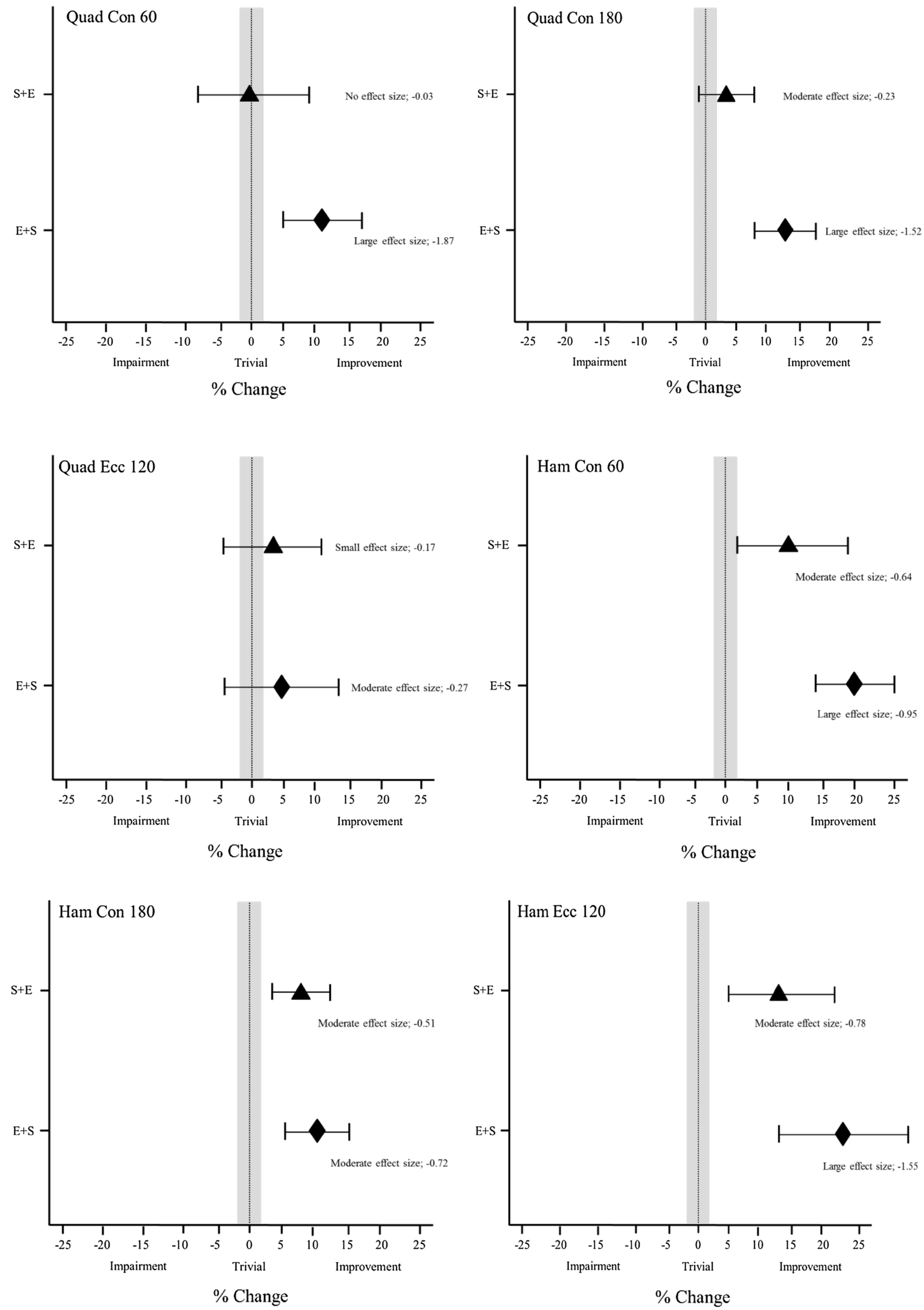
Table 2 Muscle strength data, 1RM half back squat (kg) Isometric peak force and isometric loading rate and concentric and eccentric peak torque (Nm) of the quadriceps for $S + E$ and $E + S$ experimental groups before and after training

	$S + E$						$E + S$					
	Pre	Post	% Δ	*ES*	Confidence intervals		Pre	Post	% Δ	ES	Confidence intervals	
					Upper limit	Lower limit					Upper limit	Lower limit
HBS 1-RM(kg)	121.9 ± 23.9	134.4 ± 22.10*,†	10.30 %	−0.54	10.8 to 44.9	1.3 to 5.5	115.7 ± 10.20	137.8 ± 14.10*	19.10 %	−1.79	13.5 to 64.5	1.8 to 8.8
IMVC PF (N)	628 ± 189	631 ± 136	0.60 %	−0.01	63.7 to 264.9	−253.6 to −61.0	690 ± 147	721 ± 143	4.40 %	−0.21	41.5 to 199.0	−112.5 to −23.5
IMVC LR	1018 ± 427	1225 ± 389*	20.30 %	−0.5	218.2 to 907.5	−240.0 to −57.7	1185 ± 316	1508 ± 295*	27.30 %	−1.05	41.5 to 199.0	−112.5 to −23.5
Quad Con60	218 ± 33	217 ± 31	−0.40 %	0.03	23.6 to 97.9	−100.8 to −24.2	217 ± 24	242 ± 32	11.30 %	−1.87	23.7 to 133.6	−63.7 to −13.3
Quad Con180	194 ± 22	199 ± 21*	2.50 %	−0.23	22.6 to 94.2	−78.5 to −18.9	203 ± 20	230 ± 15[a]	13.20 %	−1.52	19.2 to 108.6	−33.4 to −7.0
Quad Ecc120	262 ± 47	269 ± 29	2.70 %	−0.17	34.0 to 141.4	−118.9 to −28.6	275 ± 47	288 ± 48	4.70 %	−0.27	33.7 to 190.3	−153.9 to −32.1
Ham Con60	108 ± 18	121 ± 22*	12.20 %	−0.64	15.5 to 64.5	−22.2 to −5.3	120 ± 23	143 ± 25*	19.20 %	−0.95	15.6 to 88.3	−22.6 to −4.7
Ham Con180	106 ± 20	116 ± 19*	9.50 %	−0.51	16.6 to 69.1	−36.4 to −8.8	115 ± 14	128 ± 21*	11.20 %	−0.72	12.8 to 72.3	−35.9 to −7.5
Ham Ecc120	133 ± 23	155 ± 32*	16.80 %	−0.78	27.9 to 116.2	−15.8 to −3.8	156 ± 21	192 ± 25*	23.30 %	−1.55	18.5 to 104.3	−33.4 to −7.0

Half Back Squat 1-RM; HBS 1RM, Isometric MVC Peak force; IMVC PF, Isometric MVC Loading Rate; IMVC LR, Concentric quadriceps (60°/s); Quad Con60 Concentric quadriceps (180°/s); Quad Con180, Eccentric quadriceps (120°/s) Quad Ecc120, Concentric hamstrings (60°/s); Ham Con60, Concentric hamstrings (180°/s); Ham Con180, Eccentric hamstrings (120°/s); Ham Ecc120, squat jump (SJ) (cm), countermovement jump (CMJ) (cm), and fastest 10 and 30 m sprint time (s)

* Significant effect for time

† Significant interaction between group and time


Quad Con 60
S+E
E+S
No effect size; -0.03
Large effect size; -1.87
-25 -20 -15 -10 -5 0 5 10 15 20 25
Impairment
Trivial
Improvement
% Change
Quad Con 180
S+E
E+S
Moderate effect size; -0.23
Large effect size; -1.52
-25 -20 -15 -10 -5 0 5 10 15 20 25
Impairment
Trivial
Improvement
% Change
Quad Ecc 120
S+E
E+S
Small effect size; -0.17
Moderate effect size; -0.27
-25 -20 -15 -10 -5 0 5 10 15 20 25
Impairment
Trivial
Improvement
% Change
Ham Con 60
S+E
E+S
Moderate effect size; -0.64
Large effect size; -0.95
-25 -20 -15 -10 -5 0 5 10 15 20 25
Impairment
Trivial
Improvement
% Change
Ham Con 180
S+E
E+S
Moderate effect size; -0.51
Moderate effect size; -0.72
-25 -20 -15 -10 -5 0 5 10 15 20 25
Impairment
Trivial
Improvement
% Change
Ham Ecc 120
S+E
E+S
Moderate effect size; -0.78
Large effect size; -1.55
-25 -20 -15 -10 -5 0 5 10 15 20 25
Impairment
Trivial
Improvement
% Change

◀ **Fig. 3** Within-group relative changes in isokinetic quadriceps and hamstring strength before endurance (*S* + *E*) compared with endurance before strength (*E* + *S*) training programmes (*bars* indicate uncertainty in the true mean changes with 90 % confidence intervals). Trivial area was calculated from the smallest worthwhile change as described in the method

were significant main effects, Tukey's post hoc tests were used to locate specific differences. Data were also assessed for clinical significance using the magnitudes of change approach (Hopkins et al. 2009). Effect sizes (ES) were calculated as the difference between the means divided by the pooled standard deviation, with values of 0.2, 0.5, and above 0.8 considered to represent small, medium, and large differences, respectively (Cohen 1988). The smallest worthwhile change was calculated as 0.2 multiplied by the between-subject standard deviation, based = on Cohen ES principle (Hopkins et al. 2009). All data in text are presented as mean ± SD and $P \leq 0.05$ is indicative of statistical significance.

Results

Muscle strength

Changes in muscle strength related parameters are shown in Table 2. There were significant effects of time (i.e., pre- to post-training) for all of the measured variables ($P < 0.05$) with the exception of IMVC PF, quadriceps strength (60°/s^{CON}, 180°/s^{CON}, 120°/s^{ECC}). Training increased half back squat strength in both groups ($P < 0.01$) where the magnitude of increase was greater in the *E* + *S* condition (19.1 %) compared with *S* + *E* (10.3 %) arrangement (effect size S + E; −0.54; E + S; −1.79). Although training induced increases in isometric peak MVC force ($P = 0.391$), eccentric torque of the quadriceps at 120° ($P = 0.11$) and concentric torque of the quadriceps at 60° and 180° ($P = 0.25$; $P = 0.16$), none of these parameters reached statistical significance. Additionally, the ratio of peak eccentric hamstring and quadriceps concentric torque at 60°/s ($P = 0.15$) and 180°/s ($P = 0.23$) also did not significantly change with training. Training induced significant increases in isometric loading rate ($P = 0.02$) with moderate and large effects sizes for *S* + *E* and *E* + *S* conditions, respectively (−0.5 vs. −1.05), improvements in concentric torque of the hamstrings at 60°/s at 180°/s ($P = 0.01$ and 0.03, respectively (effect size *S* + *E*; −0.03; *E* + *S*; large −1.87), concentric torque of the quadriceps at 180°/s ($P = 0.02$) (effect size *S* + *E*; moderate −0.23; *E* + *S*; large −1.52), eccentric torque of the hamstrings at 120°/s ($P = 0.001$) (effect size *S* + *E*; moderate −0.78; *E* + *S*; large −1.55), the ratio of concentric hamstrings to

Table 3 Muscle power properties: squat jump (cm), countermovement jump (cm), and fastest 10/30 m sprint time (s) before and after the intervention period

	S + *E*						*E* + *S*					
	Pre	Post	% Δ	ES	Confidence intervals		Pre	Post	% Δ	ES	Confidence intervals	
					Upper limit	Lower limit					Upper limit	Lower limit
SJ (cm)	38.9 ± 2.9	41.8 ± 2.4*	4.40 %	−1.08	2.35 to 9.77	−7.51 to −1.8	38.0 ± 5.7	41.1 ± 5.2*	8.10 %	−0.56	1.39 to 7.87	−5.79 to −1.21
CMJ (cm)	39.2 ± 4.7	39.2 ± 3.3	−0.10 %	0	2.61 to 10.86	−0.91 to −0.22	40.7 ± 1.9	41.4 ± 2.8	−1.00 %	−0.29	2.2 to 12.45	−4.37 to −0.91
Fastest 10 m (s)	1.72 ± 0.65	1.72 ± 0.76	−0.10 %	0	0.03 to 0.14	−0.14 to −0.03	1.80 ± 0.36	1.70 ± 0.42†	−5.90 %	0.25	0.01 to 0.07	−0.35 to −0.07
Fastest 30 m (s)	4.22 ± 0.23	4.21 ± 0.20.2	−0.30 %	0.04	0.14 to 0.59	−0.62 to −0.15	4.29 ± 0.73	4.19 ± 0.12	−2.70 %	0.19	0.04 to 0.22	−0.5 to −0.1

Squat jump (SJ) (cm), countermovement jump (CMJ) (cm), and fastest 10 m and 30 m sprint time (s)

* Significant effect for time

† Significant interaction between group and time

Table 4 Mean (±SD) total muscle thickness (cm), angle of pennation (°), fascicule length (cm) before, after 5 resistance training sessions (mid) and 1 week following intervention training for $S + E$ and $E + S$

	$S + E$						$E + S$					
	Pre	Post	% Δ	ES	Confidence intervals		Pre	Post	% Δ	ES	Confidence intervals	
					Upper limit	Lower limit					Upper limit	Lower limit
MT-D	4.72 ± 0.16	4.77 ± 0.15	0.88 %	−0.32	0.12 to 0.65	−0.51 to −0.11	4.67 ± 0.45	5.08 ± 0.73	8.80 %	−0.67	0.74 to 3.07	−1.74 to −0.42
MT-M	4.79 ± 0.50	4.90 ± 0.32	2.48 %	−0.26	0.27 to 1.13	−0.75 to −0.18	4.95 ± 0.29	4.98 ± 0.39	0.55 %	−0.08	0.16 to 0.88	−0.79 to −0.16
MT-P	3.97 ± 0.39	4.01 ± 0.27	0.88 %	−0.65	0.15 to 0.63	−0.52 to −0.13	4.00 ± 0.45	4.07 ± 0.66	1.89 %	−0.12	0.21 to 1.21	−0.96 to −0.2
AoP-M	14.60 ± 1.72	15.7 ± 1.3*	7.92 %	−0.72	2.27 to 8.82	−0.81 to −0.17	14.18 ± 1.42	16.21 ± 0.80*,†	14.31 %	−1.76	3.04 to 12.66	−4.4 to −1.06
FL-M	10.34 ± 1.13	9.65 ± 1.21	−6.73 %	0.56	0.67 to 2.79	−5.03 to −1.21	11.42 ± 0.89	10.41 ± 1.6	−8.79 %	1.57	0.92 to 5.21	−8.53 to −1.78

Muscle thickness (Distal) (cm), muscle thickness (Mid) (cm), muscle thickness (Proximal) (cm), angle of Pennation (Mid) (°), fascicule Length (Mid) (cm)

* Significant effect for time

† Significant interaction between group and time

quadriceps torque at 60°/s ($P = 0.01$) and the ratio of the concentric torque of the hamstrings at 60°/s to eccentric torque of the quadriceps at 120°/s ($P = 0.05$). Whilst magnitude of change in the aforementioned parameters was, comparable between $E + S$ and $S + E$ conditions ($P > 0.05$ for all variables) differences in effect sizes for condition were observed. Relative changes and qualitative outcomes resulting from the within-group analysis are presented in Fig. 3.

Muscle power

There were significant effects of time in 10 m sprint time ($P = 0.02$) (see Table 3), ANCOVA indicated no effect of training organisation on 10 or 30 m sprint time ($P = 0.09$; $S + E$; 0; vs $E + S$; −0.25). Squat jump also significantly improved with training ($P < 0.01$) whilst no difference was evident between groups ($P = 0.84$) a large effect size was observed for the $E + S$ condition (effect size $S + E$; moderate −0.56, $E + S$; large −1.08). CMJ did not change following training ($P = 0.53$) (effect size; $S + E$; none 0; $E + S$; moderate −0.29).

Muscle morphology variables

Changes in muscle architecture before and after training are displayed in Table 4. No group interactions were observed following training; whole muscle thickness at either distal ($P = 0.15$), mid ($P = 0.33$) or proximal location ($P = 0.43$) or fascicule length ($P = 0.08$) with training. Although not significant, an 8.8 % increase in muscle thickness was observed following training in the $E + S$ experimental group at the distal location (effect size $S + E$; moderate −0.32; $E + S$; moderate −0.67). Fascicule angle of pennation increased in both groups ($P = 0.02$) and ($S + E$; 7.9 %, $E + S$; 14.3 %) a large effect size was revealed in the $E + S$ condition (effect size $S + E$; moderate −0.72; $E + S$; large −1.76).

Discussion

Using an 'ecologically valid' study design, we compared the training responses to two 'typical' 'concurrent training scenarios' used in an applied environment. Our data suggest that supplementing the habitual training practices of elite soccer players with strength training can increase muscle strength and power related variables regardless of the 'acute organisation' of concurrent training and nutrition. Although not all significant, pronounced changes and larger 'effect sizes' were observed in a range of variables in the $E + S$ training scenario (1-RM half back squat, a range of isokinetic assessments, isometric rate of force development and fascicule angle of pennation). This suggest that the concurrent training sequence, in association with the recovery duration between training bouts and the nutrient availability may be able to modulate small but clinically significant changes in physical performance parameters associated with match play. This may have practical implications for elite soccer players who routinely perform concurrent strength and endurance training on the same day.

The additional recovery period allocated in the $E + S$ allowed the participants to consume a meal between training bouts which may have helped to modulate the resultant training adaptations. The $S + E$ group had a 30- to 45-min recovery period between training bouts, whereas, participants in the $E + S$ training group had 120 min between bouts (Fig. 1). Completing two intense training exercise bouts within relatively close succession may have created considerable metabolic stress (Wojtaszewski et al. 2000). Therefore, the additional availability of key nutrients (e.g., protein and carbohydrate) before, and after each training bout in the $E + S$ condition may have helped to mitigate any additional 'metabolic stress' and subsequently promoted adaptation. Indeed, consuming protein and carbohydrate around intense training bouts can serve as a powerful modulator of many intramuscular signalling and metabolic events necessary for adaptation (Phillips 2012; Jeukendrup 2014). The $S + E$ group consumed 15 grams of protein prior to strength training, 25 g of protein between '*S*' and '*E*' training bouts and 60 g of protein following endurance training. Whereas, the $E + S$ training group consumed 60 g of protein before strength training and 25 g of protein immediately after strength training. Since protein synthesis and degradation are dependent on the presence of amino acids, the timing and quantity of protein sources consumed by the $E + S$ group may also help to explain the differences observed in muscle thickness ($S + E$ −1 % vs $E + S$ 8.8 %; effect size; −0.32 vs −0.67) and fascicule angle of pennation $S + E$ 7.9 % vs $E + S$ 14.3 %; effect size $S + E$; −0.72, vs $E + S$; −1.76) following training. The timing and quantity of carbohydrate sources available to each group may also help to explain our data. The $S + E$ group consumed 100 g of carbohydrate before completing consecutive strength and endurance training sessions. Following soccer-specific endurance training, the group then consumed approximately 140 g of carbohydrate whereas, the $E + S$ group consumed 100 g of carbohydrate before endurance training and a further 140 g of carbohydrate prior to completing the afternoon strength training session. As muscle glycogen is likely to have been the principle substrate used during the present endurance (high-intensity intermittent small-sided games) (Saltin 1973) and strength training protocols (high-load, low-repetition) (Haff et al. 2003), the additional carbohydrate consumed by the $E + S$ group before strength training may have facilitated adaptation (Tesch et al. 1986). Indeed, previous research has substantiated that carbohydrate supplementation can negate the effects of acute peripheral fatigue during a strength training bout (Haff et al. 2003). Moreover, carbohydrate availability influences the rate of skeletal muscle and whole body protein synthesis, degradation and net balance during prolonged exercise in humans (Howarth et al. 2010). Whereas, completing strength training in the face of low muscle glycogen stores can have a negative impact on training performance and adaptation (Churchley et al. 2007; Creer et al. 2005). Thus, it would seem plausible to suggest that those who performed strength training prior to endurance training ($S + E$) did not consume enough carbohydrate at the 'breakfast meal' (i.e., prior to multiple training bouts). This lack of carbohydrate availability before two training sessions may have exacerbated the training stress and blunted the adaptive response to the strength training stimulus. It is, therefore, possible to suggest that the availability of carbohydrate and protein before and after training in each training group may have modulated underlying metabolic processes which either promoted and (or) attenuated adaptations between groups.

In addition to the availability of key nutrients, discrepancies in recovery period and training sequence between groups may have also affected the participant's ability to generate force during the respective training bouts (i.e., acute fatigue). Indeed, reductions in muscle force have been observed following an acute bout of sub-maximal and high-intensity intermittent aerobic exercise, (Carroll et al. 1998; Leveritt and Abernethy 1999; Lepers et al. 2000). Localised muscle inhibition is pronounced following high-intensity muscular contraction and typically lasts between 6 and 48 h following aerobic- exercise (Fitts 1994; Lepers et al. 2000). Reductions in force capacity following an acute bout of exercise has been attributed to central (e.g., central nervous system fatigue) (McCarthy et al. 2002) and (or) peripheral mechanisms (e.g., depletion of muscle glycogen) (Haff et al. 2003). Therefore, considering that muscle glycogen may have been compromised this may have had an effect upon peripheral fatigue during secondary training bouts. Considering that higher 'resistance training' volume load (expressed as reps…sets…weight lifted) typically results in greater increases in strength when compared to low and moderate volumes (Hanssen et al. 2012). This may have had implication for the participant s in the $E + S$ exercise condition. Analysis of training load data revealed that the total 'pitch-based' training and match volume was also similar, but differences in strength training 'volume load' were apparent ($S + E$; 13443 ± 2485, $E + S$; 12341 ± 1574). The $S + E$ group completed significantly higher 'volume load' thus suggesting that the E + S group experienced some form of peripheral fatigue during the strength component of the training programme. It is therefore likely that training load factors may account of the changes observed in the present study. Given that the $E + S$ group outperformed the $S + E$ in the follow-up strength assessments, it may be hypothesised that the additional strength training stimulus in the $S + E$ may have led to over-reaching or overtraining in the subsequent testing phase. Although, without control groups performing strength exercise at the same time-of-day (i.e., 8.45 and 14:00 h) it cannot be elucidated if the 'proximity of training' (i.e., the recovery period between training bouts) or the 'exercise sequence' has caused acute interference in strength related adaptations and or created athletes to become over-reached observed in this study. Carefully controlled studies investigating the acute and chronic effects of these two exercise and nutritional arrangements are, therefore, warranted.

Whilst neurological improvements, have traditionally been regarded as sole mediator of early improvements when strength training, recent evidence suggest alterations in the architectural characteristics of the muscle can also contribute to early strength improvement (Blazevich 2006). In the present study demonstrate time effects for isometric loading rate (IMVC-LR) (a surrogate measure for neural adaptation), fascicule angle of pennation (AoP-M) and muscle thickness (MT-D). Although there were no statistical differences between groups, there were moderate and large effects observed between groups. The IMVC-LR increased by 20 and 27 % in the $S + E$ and $E + S$ groups, respectively (effect size $S + E$; −0.5, vs $E + S$; −1.76). Whereas the AoP-M increased by 7.9 and 14.3 % in the $S + E$ and $E + S$ groups (Effect size $S + E$; −0.72, vs $E + S$; −1.76). The vastus lateralis fascicule angle of pennation has previously been shown to adapt rapidly to intense resistance training interventions. For example Blazevich et al. (2003) have observed a 15 % increase in fascicule angle of pennation occurring following 10 concurrent strength and sports-specific training sessions in games players. Like the present study, this increase in pennation also correlated with improvements in strength. Although, the changes in fascicle angles of subjects in the present study are less than that of individuals who have completed resistance only training programmes. Previously authors have observed a 29 % increase in the triceps brachii (Kawakami et al. 1995) and the 34 % increase in the vastus lateralis angle after training (Aagaard et al. 2001). The attenuated changes in the present study may be attributed to the nature of the contrasting forms of muscular contraction during this study the organisation of training and or the length of the training period. Increased fascicule angle of pennation has previously been correlated to faster sprinting times in elite athletes (Abe et al. 1999; Kumagai et al. 2000). Although not a confirmatory finding, the between group difference in fascicule angle of pennation may offer some mechanistic explanation for the between group changes in muscle strength and sprinting speed observed following training. If correct, this relationship provides a unique observation that fascicule angle may become altered through modifying the organisation of concurrent training. However, it is acknowledged that whilst the type of muscular contraction can influence the way in which the fascicule adapts (Blazevich et al. 2007) this theory is speculative. Little is known about the way in which the fascicule responds to concurrent training interventions, particularly in the applied environment where there are so many confounding factors. Furthermore, not much data exist concerning the effects of nutritional interventions on fascicule remodelling. It is possible that the unique intramuscular signalling and (or) biological responses to exercise and nutritional arrangements caused the fascicule to remodel independently in each training group. Recent data suggest that when concurrent training is performed on the same day, the order and recovery time between endurance and strength training can influence the acute intramuscular signalling responses (Coffey et al. 2009; Lundberg et al. 2012, 2013). It could be suggested that the 'order' of training bouts in the $S + E$ condition may have blocked the 'anabolic' 'mTOR signalling axis'. This may have been blocked via the AMPK/SIRT-1 pathway (Kim et al. 2013) thereby limiting the activation of signalling cascades that promote strength related adaptive changes. Conversely, the 'anabolic' biological and intramuscular systems may have been up regulated for an extended period throughout the evening/night in the $E + S$ condition (MacKenzie et al. 2009). This additional 'mTOR activation time' following each strength training bout compared to the $S + E$ condition may help explain why those in the $E + S$ group outperformed their counterparts following the intervention period in a number of our outcome tests. Although, it is acknowledged that the signalling cascades responsible for fascicule remodelling are also unclear and therefore require further study. Furthermore the time course and ratio of neural and architectural adaptations during early phase resistance training programmes is not well understood. More research is required to investigate the relative contribution of neural and morphological adaptations to both isolated strength and concurrent training programmes. Due to the complex nature of these adaptations, future investigations may require multiple intramuscular and biological measurements collected in well-controlled environments.

Limitations

The authors acknowledge there are limitations to this study. Ideally, a randomised crossover controlled trial would have been utilised as observations of the adaptations to isolated strength and soccer-specific endurance training would have allowed comprehensive comparisons between each training intervention. However, due to the nature of the population and the relatively small sample size (i.e., 20 youth elite professional soccer players), it was unfeasible to have multiple experimental training groups or individuals performing isolated strength training.

Experimental groups were matched (height and weight 1RM squat strength and VO_2Max) at the start of the intervention period. However, unavoidable contact injuries ($n = 2$) and a varied training schedule ($n = 3$) associated with playing for the clubs' under-21 team subsequently created disproportionate characteristics between groups. Whilst there were no statistical differences between the groups at 'pre-training', we acknowledge that this difference may have affected the training response between groups and is therefore a limitation of the present study.

It also must be acknowledged that the present study design does not allow us to determine if it is the concurrent training sequence or if the recovery period between exercise bouts that is the mediating factor that could explain the differences observed between groups. Therefore, the discrepancy in recovery duration between experimental conditions is a limitation of this study. In addition, due to the nature of the training intervention (i.e., small-sided games) we were unable to control the aerobic stimulus between groups. Whilst there were no statistical differences in RPE training load, there were slight differences in heart-rate data. Our data show that the $E + S$ group may have achieved higher intensities during the endurance component of the training intervention. This may have been due to the fact that they did not have a strength training session immediately prior to football training; however, this conclusion is not clear without a control group completing only endurance exercise. The discrepancy in 'training intensity' could have caused interference and distorted the present findings (Wilson et al. 2012). Future research investigating the effects of concurrent training sequence in elite soccer players should aim to standardise the recovery time between training bouts and the aerobic training intensity. This approach would allow for more accurate interpretation of the mediating factors that may exacerbate the 'interference phenomenon'. Despite these limitations the study still has a number of strengths. For example, the majority of concurrent training studies investigating the effects of training organisation have used untrained participants (Hawley 2009) and incorporated training practices not representative of 'real world' practice in the English soccer leagues (Baar 2014). Therefore, we believe this design has high levels of ecological validity and may offer a starting point to suggest practical applications to soccer coaches, strength-and-conditioning practitioners and applied physiologists in elite soccer in England.

In summary, results suggest the organisation of concurrent training, recovery time allocated between training bouts and the availability nutrition may modulate small but clinically significant changes in physical performance parameters associated with match play. It is possible that performing soccer-specific endurance training and strength training within close proximity may attenuate adaptive responses following a concurrent training programme. Alternatively, separating training bouts and providing adequate nutritional intake may promote adaptations. This could be a consequence of the molecular and (or) biological responses to each concurrent training scenario. Although it is acknowledged that there are a number of confounding factors which may account for the present findings. Therefore, additional research is required to investigate the acute and chronic responses to the concurrent training programmes carried out by elite athletes in the applied setting. Understanding how athletes respond to habitual training practices could have practical implications for minimising the interference phenomenon.

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