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Investigating the Pre and Post Fatigue Relationship between Maximal Hamstring, Quadricep and Hip Strength, with Sprint Speed, and the Risk of Hamstring and ACL Injury in University Football Players

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ABSTRACT

Football player's strength and speed has been widely investigated and correlations found between the variables, with both modifiable factors for ACL and hamstring strains. Fatigue exacerbates muscular weaknesses and asymmetries, influencing injury susceptibility. The study aimed to investigate the effect of a football-specific fatigue protocol (SAFT^{45}) on concentric and eccentric quadriceps and hamstring strength, H:Q muscular imbalances, concentric hip extensor strength, hip flexor to extensor muscular imbalances, limb asymmetries and sprint speed, in relation to ACL and hamstring injury risk. Thirteen male footballers, currently competing in the British University Midlands leagues (age: 20.46 ± 1.51 years; height: 178.47 ± 5.31 cm; mass: 74.38 ± 8.83 kg; football playing age 11.08 ± 3.82 years) volunteered to participate, and participants completed two training sessions (60-90 minutes) and one match (90 minutes) per week. Any participants currently injured or with significant hamstring or ACL injury causing over 4 months out was excluded from the study. Having gained institutional ethics approval, participants were tested once, completing a crossover counterbalanced study of maximal isokinetic contractions for concentric and eccentric knee extensors; knee flexors and concentric hip extensors followed by 30 m maximal sprints, pre and post-SAFT^{45}. A significant difference was reported between pre and post-SAFT^{45} 10 m, 20 m and 30 m sprint performance (all p<.05). Significant differences existed between pre and post-SAFT^{45} NDL conHiFl:conHiEx ratio (p<.05) showing increased conHiEx:conHiFl post-SAFT^{45}. Linear regression identified DL and NDL H:Q ratios, Hcon, Hecc, Qcon and Qecc limb asymmetries are significant predictors of post-SAFT^{45} 30 m sprints (R^2=.993, p=.032). Pearson's correlation identified no significant relationships between DL or NDL H:Q ratio and conHiFl:conHiEx ratio (all p>.05). Pearson's correlation identified strong, negative and significant relationships between post-SAFT^{45} NDL to DL Qcon asymmetries at 60^o/s and 10 m (R=-.747, p=.003), 20 m (R=-.827, p<.001) and 30m sprint time (R=-.826, p<.001), however no relationships identified between pre-SAFT^{45} sprint times and any variables (all p>.05). Pre-SAFT^{45} and post-SAFT^{45} no relationship exists between H:Q and conHiFl:conHiEx ratios or asymmetries. The results suggest fatigue to not influence muscular force production, however influencing sprint performance indicating hamstring and ACL injuries to be multifactorial. For future studies, SAFT^{45} could include football-specific actions such as kicking, tackling, and jumping to closer replicate match-play and elicit muscular fatigue to better assess injury susceptibility.

Keywords: Football player's, SAFT^{45}, ACL injury, Sprints, Kicking, Tackling

INTRODUCTION

Football has been investigated greatly especially with the incorporation of science enhancing training and research. During a 90-minute match, players cover distances of 10-13 km with multidirectional low-intensity activities interspersed with 150-250 2-4 second high-intensity bouts which affect a match's outcome or induce fatigue [1]. Football requires competency in many fitness areas with strength and maximal force required for kicking, jumping and Change of Direction (COD). However, repeated sprint ability is arguably most important due to football's intermittent nature and players must be faster than opponents to score or prevent goals being scored. Positional demands affect performance with midfielders performing the most powerful movements, attackers performing the most physical contacts and maximal sprints and defenders performing the most jumping and tackling actions. Strength can be categorised as absolute strength, important in moving external objects, while relative strength is applicable for controlling body weight and greater lower limb relative strength may improve control during acceleration and deceleration events, like sprinting and improve ability to dissipate high forces and reduce injury risks [2].

The knee and hamstring are the most frequently injured areas for footballers, accounting for 25-29% and 15% of injuries respectively. Anterior Cruciate Ligament (ACL) injury incidence is 0.31 per 1000 hours with 77% of players unable to reach pre-injury performance levels, and 70% injured for a season. The biceps femoris is affected in 79% of hamstring injuries causing 90-days average training loss and hamstring injuries have one of the highest reoccurrence rates. Sprinting causes 57% of strains occurring when the hamstring eccentrically decelerates the limb to control knee extension, or concentrically when the muscle shortens forcefully to extend the hip from stance to take-off. Inadequate strength and inter-limb strength asymmetry have been identified as modifiable risk factors for hamstring injury; decreases in eccentric hamstring strength have been exacerbated by fatigue in football suggesting why nearly 50% of hamstring injuries occur in the final 15 minutes of each half [3]. Maximum hip extension occurs during kicking backswing and early swing phase of sprinting, requiring appropriate hip flexibility and strength to absorb energy, providing power and stability to lower limbs and trunk during different actions. Fatigue has been found to impair muscular performance; resulting in lower work-rate in the second half of matches than the first half with sprint number and performance reduced. A reduction in force produced by the leg extensors and flexors as the game progresses have been found, with reductions present at half-time, and further at full-time, with changes in Hamstrings to Quadriceps ratio (H:Q) observed, indicating a decreased ability to stabilize the knee joint, increasing injury risk.

Bradley and Portas, identified hip and knee Range of Motion (ROM) and strength may cause muscular strain injuries. Maximal strength has been correlated to sprint performance which is considered important in key match situations, so may be necessary to determine how fatigue influences the relationship. Repeated explosive movements are performed in football during sprinting, COD, acceleration, and deceleration, placing the hamstring group under large metabolic and mechanical demands, with high-force eccentric actions causing increased muscle damage. It has been suggested that pre-season and in-season muscular strength testing can determine load response to identify abnormal fatigue or recovery responses. Football player's strength has been investigated greatly with isokinetic testing deemed valid and reliable in strength assessments, and Isokinetic Dynamometry (IKD) considered gold standard for muscular strength assessments [4]. IKD has been used vastly to understand H:Q ratios and injuries, and there are many interpretations of H:Q ratios with both functional (Hecc/Qcon) and conventional concentric (Hcon/Qcon) H:Q ratios reported. Delextrat, Gregory and Cohen reported functional H:Q ratios more representative of the fatigue induced and actions produced in football, particularly kicking and sprinting, with functional H:Q values less than 0.7 suggesting increased injury susceptibility. Despite this, Yeung, Suen and Yeung suggested conventional H:Q values below 0.6 cause up to 17 times greater ACL or hamstring strain risk, while Lee et al., found conventional H:Q ratios below 0.505 to have increased hamstring strain likelihood. Despite this evidence, Bakken et al., suggested a single musculoskeletal screening test cannot predict future likelihood of sustaining an injury.

Research found fatigue decreased eccentric hamstring strength, effecting sprint kinematics and performance, but was not football-specific, so gaps exist in this knowledge. In football, sprint distances of 12-15 m have been found most common, indicating 10 m sprint assessments to be most game realistic, while 96% of sprints are shorter than 30 m, highlighting the importance of investigating sprint performance up to 30 m. Koklu et al., reported 10 m and 30 m sprint times have a significant relationship, while Little and Williams reported correlations between 10 m and 20 m sprint performance. Alternative studies suggested weak or no correlations between 10 m and 30 m sprint performance and strength variables. The football-Specific Aerobic Field Test (SAFT^{90}) has been used to understand how fatigue affects football performance and is understood to elicit similar magnitudes and times of the physiological, and muscle-damage markers observed throughout a match, demonstrating its external validity [5]. Despite many studies investigating SAFT^{90}, few have investigated the effects of a 45-minute fatiguing simulation and gaps exist regarding how the first half of football fatigues athletes, compared to the whole match. Despite the breadth of literature investigating speed and strength in football, a dearth in research exists regarding relationships between sprint speed, IKD strength at hips and knees and fatigue's effect on these variables. Furthermore, gaps in the literature remain surrounding how limb asymmetry affects football performance, as although kicking is asymmetrical, football is determined by bilateral competence and between-limb strength differences may help to understand performance decrements and injury prevention.

The study's purpose was to understand the effects of fatigue on the strength and speed which can be produced by university footballers. Therefore, the aim of the study was to investigate the effect of a 45-minute football-Specific Fatigue Protocol (SAFT^{45}) on concentric and eccentric quadriceps and hamstring strength, H:Q muscular imbalances, concentric hip extensor strength, hip flexor to extensor muscular imbalances, limb asymmetries and sprint speed, in relation to ACL and hamstring injury risk [6]. It was hypothesised that with fatigue, knee flexors, extensors, and hip extensors peak torque will significantly reduce. It was further hypothesised that decreased hamstring strength will be reflected by slower sprint times, reduced H:Q ratios and greater limb asymmetries.

MATERIALS AND METHODS

Participants

Thirteen male footballers (age: 20.46 ± 1.51 years; height: 178.47 ± 5.31 cm; mass: 74.38 ± 8.83 kg, football playing age 11.08 ± 3.82 years) volunteered to participate in this study. When tested, all participants were involved in the British University Men's Midlands football leagues, and completed two training sessions (60-90 minutes) and one match (90 minutes) per week. Participants were questioned on injury history with any participants currently injured or with significant hamstring or ACL injury resulting in over 4 months out excluded from the study. Having gained institutional ethics approval, all risks associated with experimental procedures were explained prior to participation and participants provided written informed content and a health screening. Protocols complied with the Helsinki declaration for human experimentation and BASES guidelines were followed throughout.

Experimental design

Participants were tested on one occasion in-season, after attending a laboratory orientation session, completing SAFT^{45} a 45-minute adaptation of the SAFT^{90}. Pre and post-SAFT^{45}, participants performed a crossover counterbalanced study of 5 maximal isokinetic contractions for concentric and eccentric knee extensors (conH, eccH) and knee flexors (conQ, eccQ), and 5 contractions for concentric Hip Extensors (conHiEx) and Hip Flexors (conHiFl), as well as 6 x 30 m maximal sprints pre-SAFT^{45} and 3 post-SAFT^{45}.

Testing procedures

Isokinetic strength assessments (pre-and post-tests): Participants performed an IKD warmup (Cybex Norm, Coventry University, UK) completing 5 repetitions at 60°/s of seated concentric and eccentric knee flexion and extension as well as supine hip extension, with 45 s rest between sets [7]. Following this, IKD measured maximal torque generated by the hamstrings, quadriceps, and hips and participants were encouraged to provide maximal effort throughout. Participants were setup in the chair and both legs were tested for 5 maximal concentric and eccentric repetitions of the quadriceps and hamstrings, during knee flexion and extension at three angular velocities deemed appropriate, 60°/s, 120°/s and 180°/s with 45 seconds between sets [8]. Participants were setup in supine to assess hip extensor strength for 5 maximal concentric repetitions at 60°/s, 120°/s, and 180°/s.

The following parameters were obtained: Peak concentric and eccentric knee flexor and extensor torques, peak concentric hip flexor and extensor torques, functional H:Q ratio, conventional concentric hip (conHiFl:conHiEx) ratio, and percentage asymmetry of Non-Dominant Limb (NDL) to Dominant Limb (DL), for quadriceps, hamstrings and hips using symmetry angle $((45^{\circ} - \arctan(L/R))/90^{\circ} \times 100)$.

Sprint assessment: Participants had 5 minutes seated recovery with Heart Rate (HR) (Polar chest strap and watch) monitored to ensure it returned to resting levels, before completing a 2-part warm-up with 5 minutes cardiovascular exercise, a treadmill jog at 60-75% maximum HR, followed by high-intensity exercise-specific activity, 3 × 30 m submaximal sprints with 30 s rest between each [9]. Participants completed 6 × 30 m maximal sprints with 30 s active recovery between each. Time to complete 30 m sprint, and 10 m and 20 m times were obtained *via* Brower speed gates placed in pairs at 10 m intervals from 0-30 m. Post-fatigue, participants completed 3 × 30 m maximal sprints with 30 s recovery between each.

Football-specific fatiguing protocol: Participants completed an adapted 45-minute half-simulation (SAFT^{45}) of the SAFT^{90} multidirectional fatiguing protocol validated by Lovell, Knapper and Small and used by Small et al., with RPE (6-20 Borg Scale) and HR assessed every 15 minutes. SAFT^{45} included a 20 m course, with four positioned navigation poles (Figure 1).

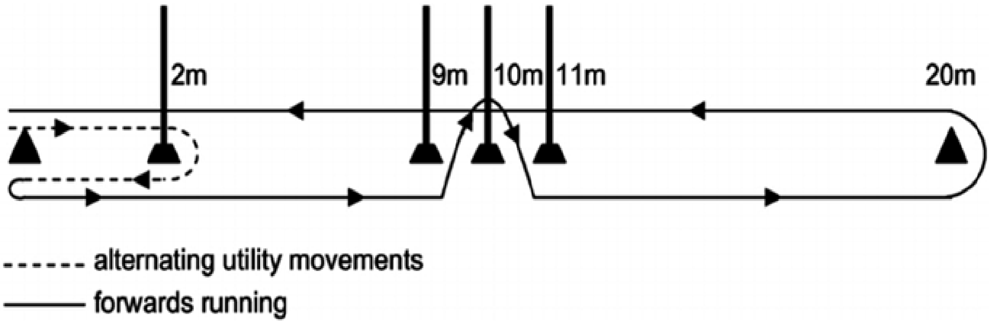

Figure 1: SAFT^{45} fatiguing protocol

Participants ran backwards or sidestepped around the first pole, before navigating the rest of the course, either standing, walking, jogging, running, or sprinting. Intensity and activity throughout SAFT^{45} were determined through the 15-minute activity profile developed by Small et al., before being repeated randomly and intermittently, three times during SAFT^{45}. Based on SAFT^{90} values, SAFT^{45} included over 600 speed changes and 650 COD, with participants walking 1.68 km, jogging 2.79 km, striding 0.75 km and sprinting 0.17 km [10].

Statistical analysis: Data were analysed using SPSS v.28.0. Data was presented as mean and SD. A paired samples T-Test examined differences between pre- and post-SAFT^{45} variables and DL to NDL. Correlations were determined for all pre- and post-SAFT^{45} variables. Multiple regression analysis was run determining strength of relationships between sprint intervals and strength variables pre- and post-SAFT^{45} [11].

RESULTS

No significant difference was reported between pre- and post-SAFT^{45} DL H:Q (p=.410), or NDL (p=.425), or between DL and NDL pre-SAFT^{45} (p=.206) or post-SAFT^{45} (p=.128) or between pre- and post-SAFT^{45} Qcon (p=.219), or Hecc strength asymmetry (p=.152).

A significant difference was reported between pre- and post-SAFT^{45} NDL conHiFl:conHiEx ratio (p=.016) showing an increase in conHiFl:conHiEx post-SAFT^{45}. No significant difference was reported between pre- and post-SAFT^{45} DL conHiFl:conHiEx ratio (p=.055), or between DL to NDL pre-SAFT^{45} (p=.269) or post-SAFT^{45} (p=.430) [12].

No significant difference was reported between pre- and post-SAFT^{45} conHiEx strength asymmetry (p=.239).

A significant difference was reported between pre- and post-SAFT^{45} 10 m (p=.007), 20 m (p=.014) and 30 m sprint performance (p=.005) showing increased sprint time and decreased performance.

Linear regression identified DL and NDL H:Q ratios, Hcon, Hecc, Qcon and Qecc limb asymmetries are significant predictors of post-SAFT^{45} 30 m sprint time (R^2=.993, p=.032), however not significant predictors of pre-SAFT^{45} 10 m (R^2=.964, p=.169), 20 m (R^2=.934, p=.289), or 30 m sprint time (R^2=.968, p=.150), or post-SAFT^{45} 10 m (R^2=.972, p=.131), or 20 m sprint time (R^2=.931, p=.302) (Table 1).

Table 1: Average maximum Hecc and Qcon torque values.

	Pre-SAFT^{45}			**Post-SAFT^{45}**		
	60º	**120º**	**180º**	**60º**	**120º**	**180º**
Max Hecc Torque (DL) (N)	116.66 ± 35.32	119.75 ± 40.79	104.60 ± 35.68	99.45 ± 18.27	110.25 ± 20.37	100.88 ± 27.96
Max Hecc Torque (NDL) (N)	116.81 ± 46.11	115.53 ± 36.22	114.32 ± 41.18	195.61 ± 26.27	204.20 ± 44.25	194.09 ± 62.38
Max Qcon Torque (DL) (N)	234.02 ± 49.16	186.38 ± 41.73	157.74 ± 40.18	203.99 ± 33.59	168.46 ± 43.82	137.46 ± 47.69
Max Qcon Torque (NDL) (N)	221.25 ± 38.15	172.31 ± 41.05	147.72 ± 41.84	203.83 ± 40.13	155.94 ± 47.46	129.26 ± 41.46

Linear regression identified DL and NDL conHiFl:conHiEx and conHiEx limb asymmetries are not significant predictors of pre-SAFT^{45} 10 m (R^2=.554, p=.575), 20 m (R^2=.609, p=.470), or 30 m sprint time (R^2=.574, p=.536), or post-SAFT^{45} 10 m (R^2=.275, p=.941), 20 m (R^2=.136, p=.994), or 30 m sprint time (R^2=.185, p=.983) (Table 2) [13].

Table 2: Average maximum HiFl and HiEx torque values.

	Pre-SAFT^{45}			Post-SAFT^{45}		
	60°	**120°**	**180°**	**60°**	**120°**	**180°**
Max conHiFl Torque (DL) (N)	129.85 ± 22.93	109.64 ± 27.91	85.09 ± 25.33	119.74 ± 29.93	104.25 ± 26.86	73.74 ± 29.00
Max conHiFL Torque (NDL) (N)	124.94 ± 24.36	109.62 ± 30.65	92.743 ± 25.58	118.31 ± 24.28	100.06 ± 29.55	80.81 ± 24.08
Max conHiEx Torque (DL) (N)	194.712 ± 73.48	152.09 ± 93.39	118.22 ± 76.91	163.22 ± 80.50	12.54 ± 91.04	97.99 ± 73.01
Max conHiEx Torque (DL) (N)	176.46 ± 56.96	148.91 ± 55.30	116.44 ± 60.13	154.59 ± 60.74	135.49 ± 78.12	106.70 ± 75.28

Pearson's correlation identified a strong, positive and significant relationship between 60°/s to 120°/s pre-SAFT^{45} H:Q for DL (R=.675, p=.011) and NDL (R=.730, p=.005) and moderate, positive relationship between 60°/s to 180°/s for NDL(R=.562, p=.045), however no significant relationship between pre-SAFT^{45} H:Q between 60°/s to 180°/s for DL (R=.523, p=.067). This indicates H:Q to be correlated at 60°/s, 120°/s and 180°/s for NDL, and at 60°/s and 120°/s for DL [14].

Pearson's correlation identified no significant relationships between pre-SAFT^{45} sprint speed and H:Q ratios (all p>.05), hamstring and quadriceps asymmetries (all p>.05), conHiFl:conHiEx ratios (all p>.05) and hip extensor asymmetries (all p>.05).

Pearson's correlation identified a strong, positive and significant relationship between 60°/s to 120°/s for DL pre-SAFT^{45} conHiFl:conHiEx (R=.694, p=.008) and NDL (R=.850, p<.001), however no significant relationship between 60°/s to 180°/s for DL (R=.296, p=.326) and NDL (R=.490, p=.090), indicating conHiFl:conHiEx to be correlated at 60°/s and 120°/s [15].

Pearson's correlation identified a strong, negative and significant relationship between pre-SAFT^{45} DL H:Q ratio at 60°/s and Qcon asymmetry (R=-.612, p=.026) and between NDL H:Q ratio at 60°/s and Hecc asymmetry pre-SAFT45 (R=-.619, p=.024) and post-SAFT^{45} (R=-.651, p=.016) (Table 3). This indicates a greater pre-SAFT^{45} Qcon asymmetry to decrease DL H:Q ratio, and pre-SAFT^{45} and post-SAFT^{45} greater Hecc asymmetry to decrease NDL H:Q ratio (Figures 2 and 3).

Table 3: Average muscular ratios.

	Pre-SAFT^{45}			Post-SAFT^{45}		
	60°	**120°**	**180°**	**60°**	**120°**	**180°**
H:Q Ratio (DL)	0.50 ± 0.13	0.65 ± 0.18	0.69 ± 0.29	0.50 ± 0.10	0.70 ± 0.22	0.84 ± 0.53
H:Q Ratio (NDL)	0.53 ± 0.18	0.69 ± 0.21	0.82 ± 0.34	0.52 ± 0.11	0.74 ± 0.24	0.81 ± 0.24
ConHiFl:ConHiEx Ratio (DL)	0.71 ± 0.15	0.91 ± 0.40	0.92 ± 0.41	0.84 ± 0.32	1.14 ± 0.60	1.00 ± 0.51
ConHiFl:ConHiEx Ratio (NDL)	0.74 ± 0.15	0.83 ± 0.40	1.01 ± 0.73	0.85 ± 0.28	0.93 ± 0.46	1.10 ± 0.69

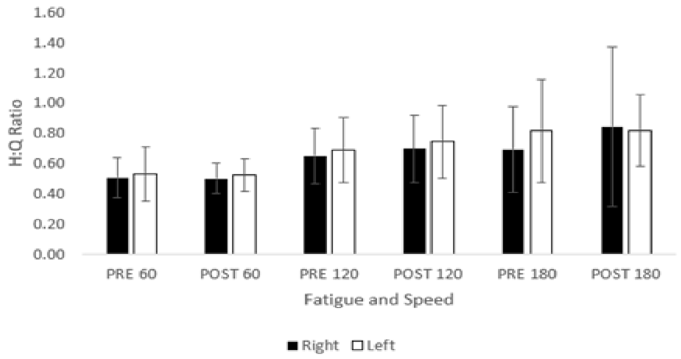

Figure 2: Pre-/post-SAFT^{45} H:Q ratios.

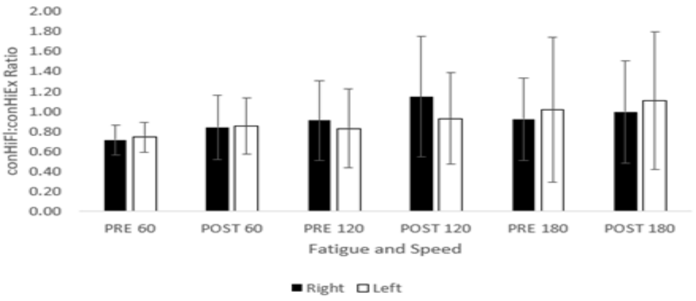

Figure 3: Pre-/post-SAFT^{45} conHiFl:conHiEx ratios.

Pearson's correlation identified a strong, positive and significant relationship between pre-SAFT^{45} 10 m and 20 m (R=.891, p<.001) and 30 m sprint time (R=.848, p<.001) and post-SAFT^{45} 10 m and 20 m (R=.956, p<.001) and 30 m sprint time (R=.930, p<.001), indicating time changes consistently across the sprint. Pearson's correlation identified no significant relationships between pre-SAFT^{45} DL H:Q ratio and conHiFl:conHiEx ratio (all p>.05) and NDL (all p>.05) or post-SAFT^{45} DL (all p>.05) and NDL (all p>.05). Pearson's correlation identified a strong, positive and significant relationship post-SAFT^{45} DL H:Q between 60°/s to 120°/s (R=.879, p<.001) and 180°/s (R=.765, p=.002) and NDL post-SAFT^{45} H:Q between 60°/s to 120°/s (R=.650, p=.016) and 180°/s (R=.639, p=.019) (Table 4 and Figure 4) [16].

Table 4: Average sprint performance.

	Pre-SAFT^{45}	**Post-SAFT^{45}**	**P Values**
10 m Sprint (s)	1.82 ± 0.12	1.87 ± 0.11	0.007
20 m Sprint (s)	3.14 ± 0.18	3.22 ± 0.17	0.014
30 m Sprint (s)	4.39 ± 0.24	4.49 ± 0.27	0.005

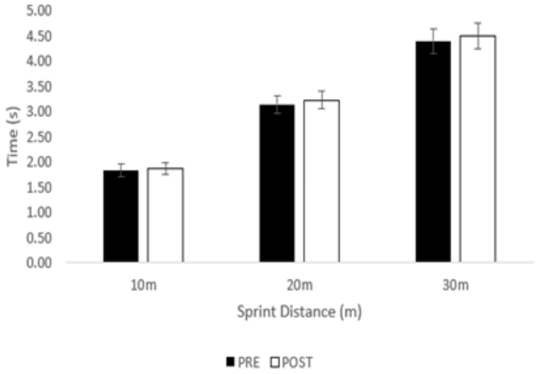

Figure 4: Pre-/post-SAFT^{45} sprint performance.

Pearson's correlation identified a strong, negative and significant relationship between post-SAFT^{45} Qcon asymmetries at 60°/s and 10 m (R=-.747, p=.003), 20 m (R=-.827, p<.001) and 30 m sprint time (R=-.826, p<.001), indicating as asymmetry percentage increases, DL is stronger and sprint time decreases, however no significant relationships were identified between post-SAFT^{45} sprint speed and H:Q ratios (all p>.05), conHiFl:conHiEx ratios (all p>.05) and hip extensor asymmetries (all p>.05) for all speeds and DL or NDL.

Pearson's correlation identified a strong, positive and significant relationship post-SAFT^{45} conHiFl:conHiEx between 60°/s to 180°/s for DL (R=.658, p=.015) and NDL between 60°/s to 120°/s (R=.836, p<.001) and 180°/s (R=.833, p<.001) however no significant relationship exists between 60°/s to 120°/s for DL (R=.296, p=.326) indicating conHiFl:conHiEx to be correlated at 60°/s, 120°/s and 180°/s for NDL and 60°/s to 180°/s for DL (Figures 5-7).

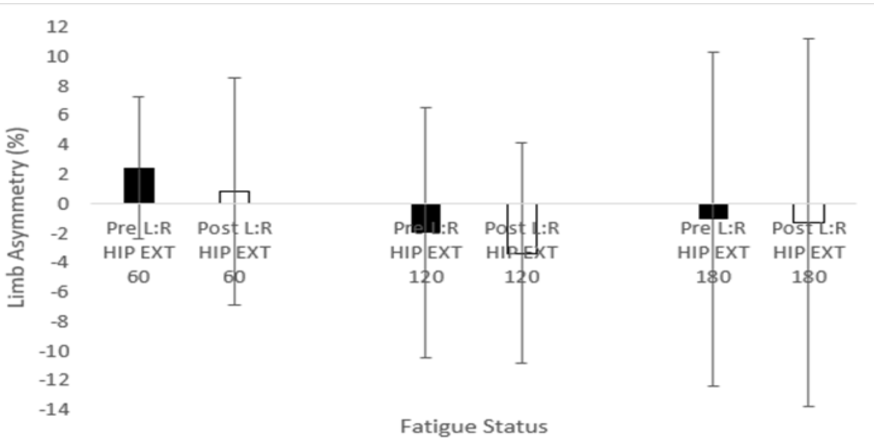

Figure 5: Pre-/Post-SAFT^{45} hip asymmetries.

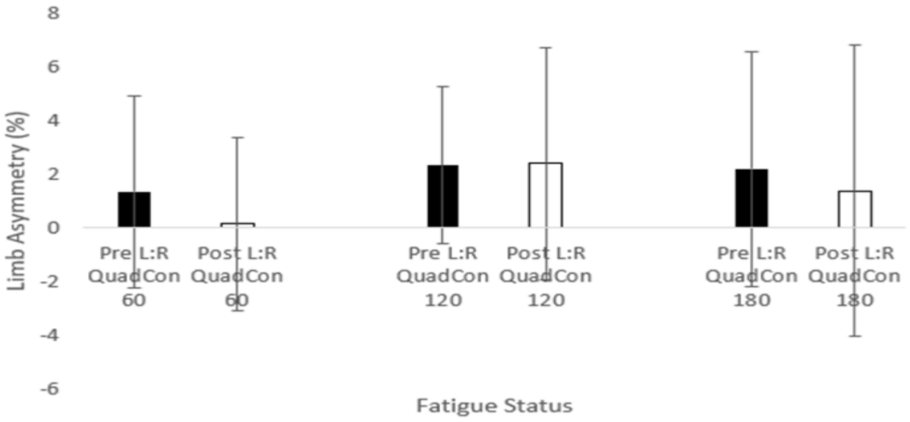

Figure 6: Pre-/Post-SAFT^{45} concentric quadriceps limb asymmetries.

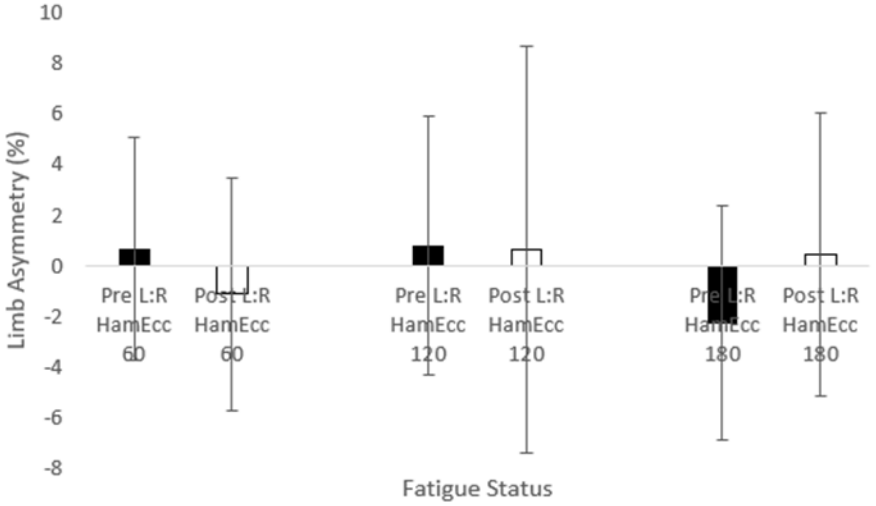

Figure 7: Pre-/Post-SAFT^{45} eccentric hamstring limb asymmetries.

DISCUSSION

The study aimed to investigate the effect of SAFT^{45} on Qcon, Qecc, Hcon, Hecc strength, H:Q muscular imbalances, conHiEx strength, conHiFl:conHiEx muscular imbalances, limb asymmetries and sprint speed in relation to ACL and hamstring injury risk [17].

The results indicate fatigue does not influence H:Q ratio, Qcon or Hecc limb strength asymmetries, however fatigue significantly improved NDL conHiFl:conHiEx ratios, but not DL or hip extensor limb strength asymmetries. Fatigue influenced sprint performance, with significantly slower times post-SAFT^{45} at 10 m, 20 m, and 30 m. The results indicate relationships exist post-SAFT^{45} between DL and NDL H:Q ratios, Hcon, Hecc, Qcon and Qecc limb asymmetries and 30 m sprint time, indicating hamstring and quadriceps ratios and asymmetries can predict post-SAFT^{45} 30 m sprint time. No relationships were established between pre-SAFT^{45} or post-SAFT^{45} hip flexor values and sprint speed, indicating hip ratios and asymmetries to not influence sprint performance [18]. The study demonstrates no correlations between pre-SAFT^{45} sprint speed and knee and hip ratios and asymmetries, meaning they do not influence one another, however, post-SAFT^{45} a negative correlation exists between conQ asymmetries and sprint performance, suggesting as DL strength became greater than NDL strength, sprint performance increased, suggesting DL weakness limits sprint ability. However, no correlations were established between post-SAFT^{45} sprint time and any other variables. Correlations were identified between pre-SAFT^{45} DL H:Q ratio at 60°/s and Qcon asymmetry percentage and between pre-SAFT^{45} NDL H:Q ratio at 60°/s and Hecc asymmetry percentage, identifying their influences on one another. No correlations were found between H:Q ratios and conHiFl:conHiEx ratios, meaning no effect upon one another [19].

In line with the hypothesis, slower sprint times were present post-SAFT^{45}, indicating fatigue effected sprint performance. Contrary to the hypothesis, post-SAFT^{45} peak torque, ratios and asymmetries at the knee and hip did not decrease suggesting SAFT^{45} to not negatively affect stability and asymmetries, and in some circumstances increase stability, such as conHiFl:conHiEx.

The results suggest fatigue to not influence eccentric hamstring strength as suggested by Greig, but sprint kinematics and performance were influenced as suggested, a plausible explanation could be because the study uses a football-specific protocol, unlike Greig. The results contradict the claims of Reilly, Drust and Clarke that reductions in H:Q ratio would be present at half-time post-fatigue indicating decreased knee joint stability, instead the results suggest H:Q ratio and therefore knee stability increase post-SAFT^{45}, with increases in Hecc strength present in Table 1, contradicting Gleeson et al., that there would be increased injury risk. The results suggest DL H:Q ratio and Qcon asymmetry are correlated pre-SAFT^{45}, and NDL H:Q ratios are correlated to Hecc asymmetry pre-SAFT^{45}, therefore suggesting pre-SAFT^{45} DL Qcon and NDL Hecc to influence knee stability and injury susceptibility. The results show no correlations between sprint performance and muscular strength post-SAFT^{45}, but regression was found between 30 m sprint and knee flexor and extensor ratios and asymmetries suggesting muscular strength does not impact sprinting ability, but to an extent can predict the expected values of one another. Although the results suggest fatigue to not influence muscular force production, it is shown to influence sprint performance, and therefore suggests sprinting could influence hamstring and ACL injuries more than muscular instabilities and asymmetries [20].

The study provides insight into how fatigue may affect footballers and displays that fatigue influences sprint performance, but does not significantly influence H:Q ratio, or limb asymmetries, therefore building on Bakken et al., that a single musculoskeletal assessment, like H:Q may not be an effective predictor of ACL or hamstring injury risk and instead multiple variables are influencing injury susceptibility. The results could be considered when investigating injuries in football; injury prevalence is greater at the end of either half, however research suggested this was caused by eccentric overload, suggesting limb asymmetries or decreases in H:Q ratios cause this. However, the results show fatigue influences conHiFl:conHiEx and builds on Henderson, Barnes and Portas suggesting hip strength to influence muscular strain injuries. While previous research has focused on the effects of SAFT^{90} on performance and found a football match to influence strength and speed, these results demonstrate a football half to not induce the same fatiguing responses and may suggest with appropriate half-time recovery interventions and the introduction of more substitutes permitted during a match, improved performance levels and reduced injury risk may occur.

CONCLUSION

The study has a few limitations which should be noted. Although SAFT^{45} replicated match play, exercise choice and intensity were in a pre-determined order so did not represent football's random nature or include any football-specific actions like kicking, tackling, or jumping which may elicit muscular fatigue in a game, making the protocol closer to a match replication. The data reliability may be impacted by SAFT^{45} duration; this study only used a half-simulation, whereas previous studies used SAFT^{90} simulating a full match; so fatigue may not have been induced during SAFT^{45}, as previously in SAFT^{90}. The sample size was constrained to male university footballers, so data may not be transferrable to other populations, like professionals or female athletes, where responses may differ.

Future research could investigate this study in female athletes because women have significantly reduced neuromuscular control, causing greater knee valgus, combined with lower hamstring strength, and therefore increased ACL injury risk compared with men. Future studies should consider SAFT^{45} only simulated a football half and given the lack of research surrounding hip strength, speed, and fatigue, could investigate this further using SAFT^{90} or a different fatiguing protocol. In conclusion, SAFT^{45} influences sprint performance, suggesting hamstring and ACL injuries caused by sprint performance deterioration are multifactorial and not solely by muscular deficits.

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