The effects of soccer simulation on isolated lumbar extension force and trunk flexor force

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ABSTRACT

Force production from the trunk flexors and lumbar extensors might be important for maintaining optimal kinematics during physical tasks such as running. This study measured isolated lumbar extension strength and trunk flexor endurance before and after simulating soccer. Reductions in force output between flexors and extensors were compared, alongside non-local muscle fatigue (hand grip). Lumbar extension strength was also compared to untrained, recreationally trained, and powerlifters as these muscles do not appear to strengthen from resistance training. The results showed soccer players' lumbar extension strength differs to untrained populations (p=0.02) but not to recreationally trained populations (p=0.266), displaying similar strength to powerlifters. Lumbar extension strength changed by −2767 ± 1860 N·m·deg (p=0.01) after soccer simulation but no change was found for trunk flexion endurance (−3s [IQR: −8–7 s]; p=0.419). After converting to percentage change, the reduction in lumbar extension strength was significantly greater than the reduction in hand grip (p=0.026). The findings showed lumbar extensor fatigue is greater than in the trunk flexors. This is particularly important as the lumbar extensors cannot be strengthened optimally without pelvic restraints. Research should establish the consequences of lumbar extensor fatigue after soccer on performance measures and injury risk factors.

INTRODUCTION

Schuermans *et al.* (2017a) found increased anterior pelvic tilt whilst running in prospectively hamstring injured participants, and force production from the trunk muscles is suspected to be responsible (Schuermans *et al*. 2017b). The rectus abdominis can resist anterior rotation of the pelvis according to its anatomical attachments (Mann, Moran, and Dougherty, 1986). Therefore, reduced force output in the trunk flexors may explain Scheurmans *et al.*'s (2017a) findings. Alternatively, reduced force output in the trunk extensors could be to blame. Higashihara et al. (2015) found increasing forward lean by approximately 16°, of which 6.2° was spine flexion as evidenced by the trunk angle exceeding the pelvis in the laboratory reference frame, is accompanied by increased anterior pelvic tilt. Indeed, Bonte *et al.* (2015) found participants with a history of hamstring injuries display lower erector spinae activity during running and a more flexed thorax.

The increased anterior pelvic tilt observed by Schuermans *et al.* (2017a) was observed whilst running without fatigue, but it may be that participants susceptible to injury represent a sub-set of the population which possesses less strength at rest, whereas for others sufficient weakness may occur only after fatigue. Further, the increased anterior pelvic tilt observed by

Schuermans *et al.* (2017a) may become even greater after fatigue and at least partially explain the increase in injury incidence with match duration in sports such as soccer (Woods *et al.* 2004).

Fatigue in the trunk flexors and extensors has been demonstrated after soccer simulation (Fransson *et al.* 2018), but these measurements are without comprehensive pelvic restraints, meaning the reductions in trunk extensor torque could reflect reductions in hip extensor torque. Furthermore, the lumbar extensors (lumbar portion of erector spinae) are unique in that they are typically weak and cannot be strengthened without first preventing the sagittal rotation of the pelvis (Steele, Bruce-Low and Smith 2015; Fisher, Bruce-Low and Smith 2013), likely because of the dominance of the hip extensors, as proposed by the deconditioning hypothesis (Steele, Bruce-Low and Smith, 2014). Whether fatigue in the lumbar extensors occurs in exercise without restraints might be a mundane notion to the unfamiliar reader, especially considering muscle activity is large during high-speed running (Saunders. *et al.* 2005); but both Romanian deadlift training and hip thrust training fail to increase lumbar extensor torque across the entire range of motion despite inducing high activity (Hammond *et al.* 2019; Fisher, Bruce-Low and Smith 2013). Indeed, Vigotksy has shown that muscle activity from EMG cannot be used as an indicator of strength or hypertrophy outcomes (Vigotsky et al. 2018) and Steele, Bruce-Low and Smith (2015) highlighted a lack of agreement between exercises with high lumbar EMG activity and strength development.

Although not certain, it seems likely that lumbar extensor fatigue is possible as seen after performing a series of trunk extension movements such as kettlebell swings (Edinborough, Fisher and Steele 2016), but no research has examined the fatiguing potential of exercise outside of the resistance training modality, such as soccer. Studies that claim to have fatigued the lumbar extensors or erector spinae may have fatigued the hip extensors, preventing causal inferences regarding the lumbar extensors *per se*, or used an arbitrary degree of fatigue that has little relevance for external applications (Hart *et al.* 2009; Champagne, Descarreaux and Lafond 2008).

Theoretically, repeated running and sprinting over a 90-minute duration is a potent prescription for inducing lumbar extensor and trunk flexor fatigue. However, the demands of soccer are variable and not conductive to systematic investigation for causal effects. The coefficient of variation in sprints between match play is large (37.1%; Carling *et al.* 2016). An alternative that would provide proof of concept with an estimate that should be accurate on average and over many games, is soccer simulation. Such protocols are used extensively in the literature for investigating similar variables (Silva *et al.* 2018; Fransson *et al.* 2018). Therefore, the aim of this study is twofold. First, to compare maximum isolated lumbar extension (ILEX) torque between soccer players and non-soccer players to see if soccer participation and the involved high-speed running has conditioned these muscles. Second, to assess whether lumbar extensor fatigue is possible after performing a soccer simulation and if so, comparing the magnitude of fatigue to that in the trunk flexors. It is hypothesised that soccer is not sufficient to strengthen the lumbar extensors. Also, it is hypothesised that fatigue will occur in the lumbar extensors and the trunk flexors, but the magnitude of fatigue will be greater in the lumbar extensors.

METHOD

Study design

The investigation took the form of two independent studies. The first measured isolated lumbar extensor torque before and after a soccer simulation, along with heart rate to measure the internal physiological demands. The second study measured trunk flexion endurance before and after soccer simulation, as an indicator of fatigue in these muscles. Maximum hand grip strength was also measured before and after soccer simulation as a measure of non-local fatigue. This allowed for tests to see whether fatigue in the lumbar extensors and trunk flexors force were due to non-local factors. Ethical approval for this study was granted by the Health, Exercise and Sport Science Ethics committee at Solent University. Informed consent was obtained in writing after participants read an information sheet about the study.

Study 1 Participants

Twelve, male amateur soccer players (age: 20 ± 4 years; Stature: 179.4 ± 5 cm; mass: 72 ± 7 kg) were recruited for this study (five defenders; three attackers; four midfielders). Participants were obtained by contacting local soccer teams or through direct contact and word of mouth. Inclusion criteria required participants to be currently assigned to a club as an outfield player and were excluded if they had any lower limb or back injuries. According to the English national league system, most players participated at level 10 (mode) and ranged between levels 8–15. Three participants competed in university or college leagues.

Study 1 Procedure

This study took a within-subjects repeated measures design. ILEX strength was measured pre- and post a soccer simulation protocol (Soccer-specific Aerobic Field Test [SAFT90]) and heart rate was measured throughout. Participants were asked to attend a laboratory on two occasions separated by at least 72 hours. The initial session familiarised participants with the procedure for ILEX testing and the soccer simulation to ensure reliability. The ILEX device (MedX, Ocala, FL, USA) restricts movement to the lumbar spine only through a series of restraints that prevents pelvic rotation (figure 1) and has demonstrated strong test-retest reliability ($r = 0.81–0.97$; Graves et al. 1990). Likewise, our laboratory has reported similar reliability (within-day $r = 0.90–0.99$). The device has a minimum detectable change of 1286 N·m·deg according to the calculations of

Weir (2005) and the raw control group test-re-test data of previous work (Stuart et al. 2018; Edinborough, Fisher and Steele 2016). Heart rate (TS1, Polar, Finland) was recorded every 15 minutes throughout the SAFT90 including the half-time 15-minute rest period. Upon completion of the SAFT90, participants were allocated five minutes rest before repeating the ILEX isometric strength test as per baseline. The five minutes rest allowed sufficient time for the participant to be re-positioned and secured in the ILEX device.

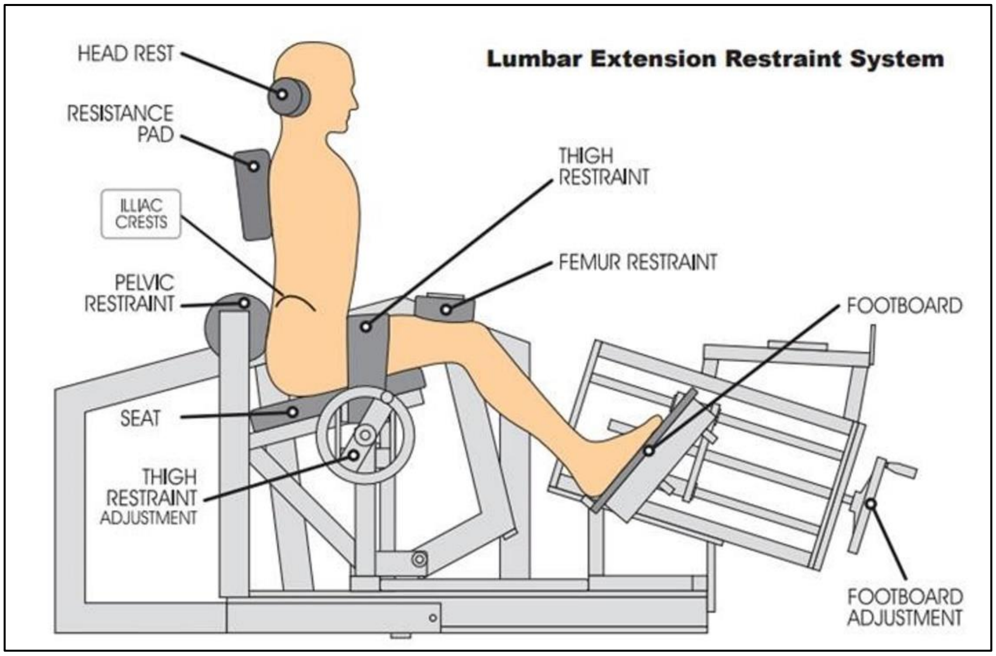


Figure 1: A schematic representation of the ILEX device and its restraints

Study 1 Lumbar extension strength testing

The testing procedure for ILEX strength began with a dynamic warm up of eight repetitions across a full range of motion using a load of 27 kg and a repetition duration of 2:4 s for concentric and eccentric portions respectively. Immediately following the warmup, lumbar extension strength was measured isometrically across the range of motion (72°–0°), beginning in full flexion and progressing towards full extension by 12° intervals. At each angle participants were asked to gradually increase the force up to maximal effort over a three second duration and verbal encouragement was provided throughout. Between each angle participants rested for approximately 10 seconds, during which they were passively moved across the ROM.

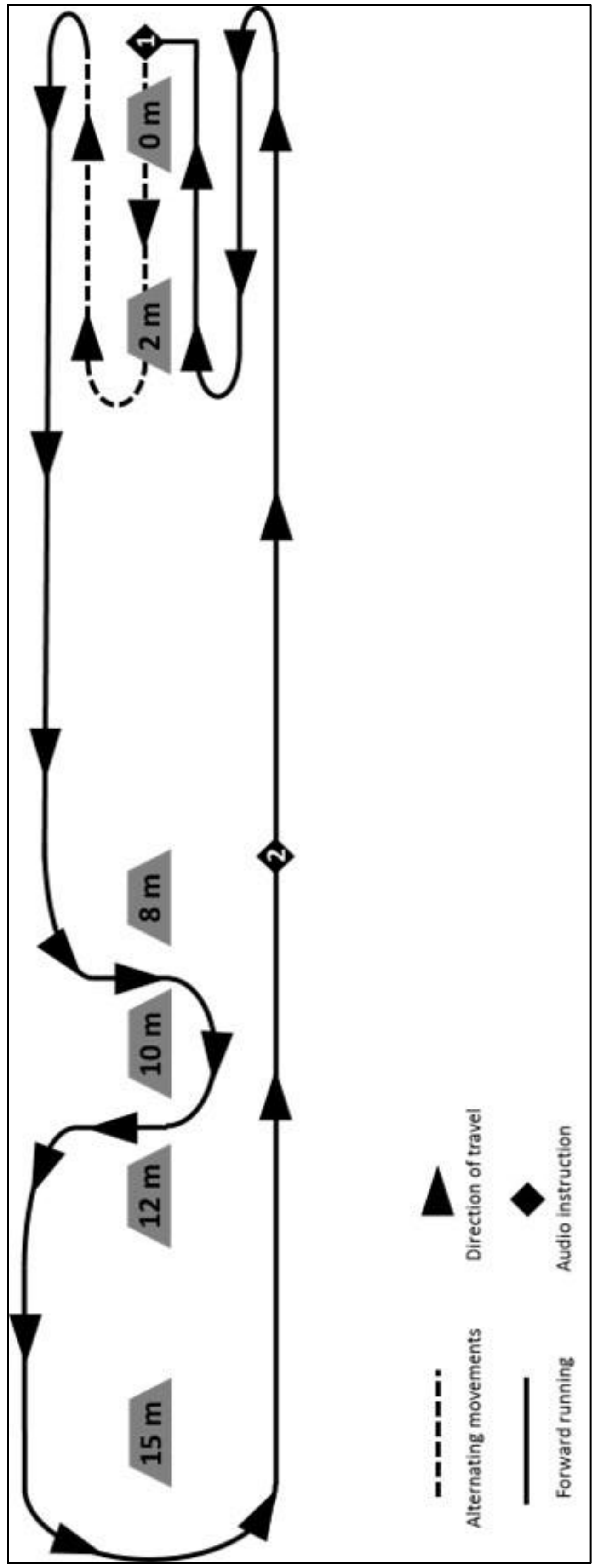
Study 1 Soccer simulation

After baseline testing, participants were allocated a brief seated rest period and were fitted with a heart rate monitor. At the end of the rest period, baseline heart rate was measured and the soccer simulation protocol began. The soccer simulation (SAFT90; Lovell, Knapper and Small 2008) is a 90 min protocol separated by a 15-minute passive rest after 45 minutes (course shown in figure 2). The 15-minute passive rest was to represent the half-time interval in soccer. The Loughborough intermittent shuttle test (LIST) and the SAFT90 are the principal simulations used by prior research (85% of all on-field simulations; Silva *et al.* 2018), but unlike the LIST, the SAFT90 has an activity profile more specific to soccer with a duration of 90-minutes (plus 15 minutes rest) and change of direction tasks compared to the LIST's linear movement profile and frequent rest periods.

The SAFT90 consists of repeated linear and alternating movements (side-steps, change of directions, and backwards running) with commands provided via pre-recorded audio. A variety of speeds are used consisting of stationary, walking, jogging, striding, and sprinting. Participants were asked to maintain the required effort. Participants who could not keep up with the speed would catch up on slower phases such as walking portions, although this was limited to the faster 'stride' (90-95% effort) and 'sprint' (100% effort) portions of the simulation. This procedure has been used extensively in the literature to simulate football as it is valid with regards to the physiological and mechanical demands (Lovell, Knapper and Small 2008), and allows for comparable results between studies (Rhodes, McNaughton and Greig 2019; Lovell *et al.* 2018; Marshall *et al.* 2014; Small *et al.* 2009).

The simulation was completed indoors on hard flooring to remove variability in the surface conditions due to weather. For the protocol to fit in the laboratory space, the protocol was modified similarly to that of Azidin *et al.* (2015). The course length was reduced by 5 m, from 20 m to 15 m. To ensure the total distance covered remained similar, participants were required to travel out the 2 m cone and return to the start before beginning the next instruction. Total course length was reduced by 6 m but added an additional three changes of direction for every completion of the course. This was not considered to affect the validity of the simulation given that match-to-match variability is large in soccer (Carling *et al.* 2016).

Figure 2: The adapted SAFT90 protocol



Study 1 Data analysis

A strength curve for the participants' ILEX strength was generated using the peak torque at each angle. ILEX strength was measured as the area under the torque-angle curve using the trapezoidal method and is reported as the strength index (SI). The area for a single trapezoid (A) is calculated as:

$$A = \frac{a+b}{2}h$$

Where *a* and *b* are the peak torque values for two consecutive angles and *h* is the difference in degrees between the two angles, which is constant at 12° in this scenario. The SI was equal to the sum of these trapezoidal areas.

Study 2 Participants

Ten, male amateur soccer players (age: 22 ± 4 years) were recruited for this study (three defenders; four attackers; three midfielders). Participants were obtained by contacting local soccer teams or through direct contact and word of mouth. Inclusion criteria required participants to be currently assigned to a club and compete as an outfield player. They were excluded if they had any lower limb or back injuries. According to the English football league system, most players most participated at level 10 (mode) and ranged between levels 7–15.

Study 2 Procedure

Trunk flexion endurance and maximum hand grip strength was measured pre- and post the SAFT90 soccer simulation. Participants were initially familiarised with the SAFT90 protocol (if they had not been previously) and the hand grip and trunk flexion endurance tests.

Study 2 Trunk flexion endurance and hang grip strength testing

Trunk flexion endurance was measured using McGill's isometric trunk flexion endurance test, which has good reliability (ICC: 0.97; McGill, Childs and Liebenson 1999). The trunk flexor test was adapted to limit contributions of the hip flexors and control the change in lumbar lordosis angle as participants reported it primarily fatigued the hip flexors. Participants laid supine with their palms pronated and shoulders relaxed. Participants were instructed to ‘curl-up’, raising their scapulae off the ground and allowing their fingers to slide forwards with the trunk. The change in lordosis angle was standardised by ensuring participants’ third finger displaced by 10 cm, confirmed by contacting a wooden block that measured 10 cm away from the participants’ third finger when laying silently in supine. A 10 cm displacement was chosen as it increases activation of the lower abdominal muscles (Parfrey *et al.* 2008). To minimise hip flexor involvement, knees were bent to approximately 90° and feet had to remain in contact with the ground without external fixation (Parfrey *et al.* 2008). A 5 kg weight was placed on the sternum to add additional load. The additional weight increase prevented task failure due to factors such as tedium. Once a 10 cm displacement had been achieved with the third finger, the time was recorded until the participant could no longer maintain contact with the wooden block. Throughout the task, participants were given strict instructions to relax their shoulders and elbows, and this was monitored by the investigator throughout. Participants were familiarised with the task prior to completing the test and verbal encouragement was provided throughout. All participants received a demonstration of the task and practiced with feedback the until the correct technique was used.

Hand grip strength was measured in the participant’s preferred hand using a dynamometer (5101 Grip-D, Takei, Japan) with the shoulder adducted and the elbow flexed to 90°. Participants were encouraged to provide a maximal effort over 3 s. Participants were given one practice attempt, followed by three recorded attempts. A rest period between each attempt was allocated. After measuring hand grip and trunk flexion endurance, participants completed the SAFT90 protocol identically to that in study 1 of this investigation, including the 15-min rest to represent half time. Upon completion of the SAFT90, participants immediately repeated the three measures of hand grip strength. After five minutes since completing the SAFT90, participants repeated the trunk flexion endurance task. The 5-minute delay was chosen to align with the 5-minute delay used when measuring ILEX fatigue in study 1 and allowed for a comparison between the two measures. Hand grip strength was averaged across the three attempts using a mean in each condition and this value was used for statistical analysis.

Statistical analysis

For study 1, statistical analyses were performed using SPSS (Version 25; IBM Corp. 2019). To assess whether soccer players had similar lumbar extensor force to others, the baseline SI was compared to the SI in other populations. These were asymptomatic individuals from Conway *et al.* (2018), and recreationally strength trained, non-competitive powerlifters and competitive powerlifters from Androulakis-Korakakis *et al.* (2018). The assumption of normality for all baseline SI data was assessed through a Shapiro-Wilk's test, which failed to reject the assumption of a normal distribution for all but the asymptomatic group ($W = 0.935$, df = 42, $p = 0.019$). Therefore, baseline SI data were reported as means and SDs apart from the asymptomatic group where data was represented as medians and IQRs. To test the hypothesis that soccer players' ILEX SI differs to asymptomatic controls, a two-sided Mann Whitney U test was used. If this was significant then comparisons were made between soccer players and recreationally trained subjects using a two-sided independent t-test. Both inferential statistics had an alpha of 0.05.

For the change in SI after soccer simulation, a Shapiro-Wilks test failed to reject the assumption of a normal distribution ($W = 0.915$; df =10; $p = 0.280$) and was confirmed through visual inspection. Therefore, descriptive statistics for the change in SI scores are presented as mean and standard deviations. SI change scores were assessed using a single sample t-test against a value of 0 and deemed significant if the probability of these findings under the null hypothesis (no change) was less than 5% ($p < 0.05$). The precision of the findings was assessed through a 95% confidence interval. Heart rate data were reported descriptively to assess the external validity of the study by comparing to semi-professional soccer players completing the SAFT90 (Lovell, Knapper and Small 2008).

For study 2, statistical analyses were conducted in JASP (Version 0.14.1). A Shapiro-Wilk's test was unable to reject the assumption of normality for the change in hand grip data (W = 0.959; $p = 0.776$) but did reject a normal distribution for the change in trunk flexion data (W = 0.767; $p = 0.006$). A one-sided one sample t-test was used to test the null hypothesis that the change in hand grip strength was greater than 0 (i.e., hand grip strength improved). A one-sided Wilcoxon signed-rank test was used to test the null hypothesis that the change in trunk flexion endurance time was greater than 0 (i.e., trunk flexion endurance improved). Both tests had an alpha of 0.05.

The change in trunk flexion endurance time, change in SI, and change in hand grip strength after soccer simulation were converted to percentage change to allow comparisons between each muscle. Percentage change data for each muscle was normally distributed according to Shapiro-Wilk's test ($p > 0.05$) but trunk flexion change had a positive skew (1.27) on further inspection. If trunk flexion endurance or ILEX SI were found to decrease after the SAFT90, then a one-sided independent t-test was used to test the null hypothesis that the percentage reduction in either ILEX SI is less than the percentage reduction in non-local muscles (change in hand grip strength), or a one-sided Willcoxon signed rank test would be used to compare trunk flexion data to non-local muscles. This was a more rigorous test of whether local lumbar extensor or trunk flexor fatigue occurred after the SAFT90 or whether non-local mechanisms were responsible. Descriptive statistics for the percentage change for all muscles were reported using medians and interquartile ranges for comparison.

Results

Descriptive statistics for baseline SI in soccer players compared to other populations are presented in table 1. Inferential statistics rejected the null hypothesis that soccer players' SI does not differ to asymptomatic populations (asymptotic $p = 0.02$) but was unable to reject the null hypothesis that soccer players' SI does not differ to recreationally trained subjects ($t_{(45)} = -1.127$; $p = 0.266$). A visual comparison of SI values between populations (including powerlifters) is presented in figure 3.

One outlier was removed from the SI change data due to an increase in force after soccer simulation that exceeded the typical minimum detectable change (figure 4), indicative of a true improvement. It was confirmed that the initial test was not reflective of their maximal strength after further tests. Therefore 11 participants were analysed for changes in SI. All participants achieved a full ROM on the ILEX device. With the outlier removed, the mean change in SI scores after soccer simulation was −2767 ± 1860 N·m·deg (13% of baseline), and was statistically significant ($t_{(10)} = -4.933$; $p = 0.01$. Heart rate averaged 166 ± 3 $b{\cdot}m^{-1}$ across all time points, which is descriptively similar to the 162 ± 2 $b{\cdot}min^{-1}$ reported in semi-professional soccer players performing the SAFT90 protocol.

The median trunk flexion endurance time at baseline was 63 s with an interquartile range of 46–122 s. The median change in trunk flexion endurance time was −3 s with an interquartile range of −8–7 s. Inferential statistics for the change in trunk flexion endurance time failed to reject the null hypothesis that the change in time was greater than 0 ($V = 25$; $p = 0.419$).

The mean hand grip strength at baseline was 41.8 ± 5.6 kg. The mean change in hand grip strength was -2.2 ± 4.1 kg. Inferential statistics for the change in hand grip also failed to reject the null hypothesis that the change in hand grip strength was greater than 0 ($t_{(9)} = -1.664$; $p = 0.065$).

A one-sided independent sample t-test rejected the null hypothesis that the percentage change in handgrip strength is less than the percentage change in ILEX SI ($t_{(19)} = 2.072$; $p = 0.026$). Comparisons between the change in trunk flexion time and hand grip strength were not conducted as trunk flexion endurance was not found to statistically reduce after the SAFT90.

Comparisons of the percentage change in trunk flexion endurance time, change in SI, and change in hand grip strength are presented visually in figure 5. The median change in the trunk flexion endurance time was similar to the change in hand grip strength (−4.5% [29%] and −6% [12.8%] respectively). The change in SI was greater at −13% (5.5%) with one participant displaying an increase in SI after the SAFT90.

Figures and Tables

Table 1: Comparison of Isolated lumbar extension SI between different populations

Sample	Mean SI (N·m·deg)	SD	N	Mean Age (SD)
Soccer players	21836	5509	11	20 (4)
Asymptomatic*	13925	10519	42	30 (12)
Recreationally trained	23771	4823	36	25 (6)
Non-competitive powerlifters	23019	6843	10	24 (3)
Competitive powerlifters	22815	5812	13	32 (8)

Note: *SI data for asymptomatic sample is presented as Median and IQR as data did not resemble a normal distribution.

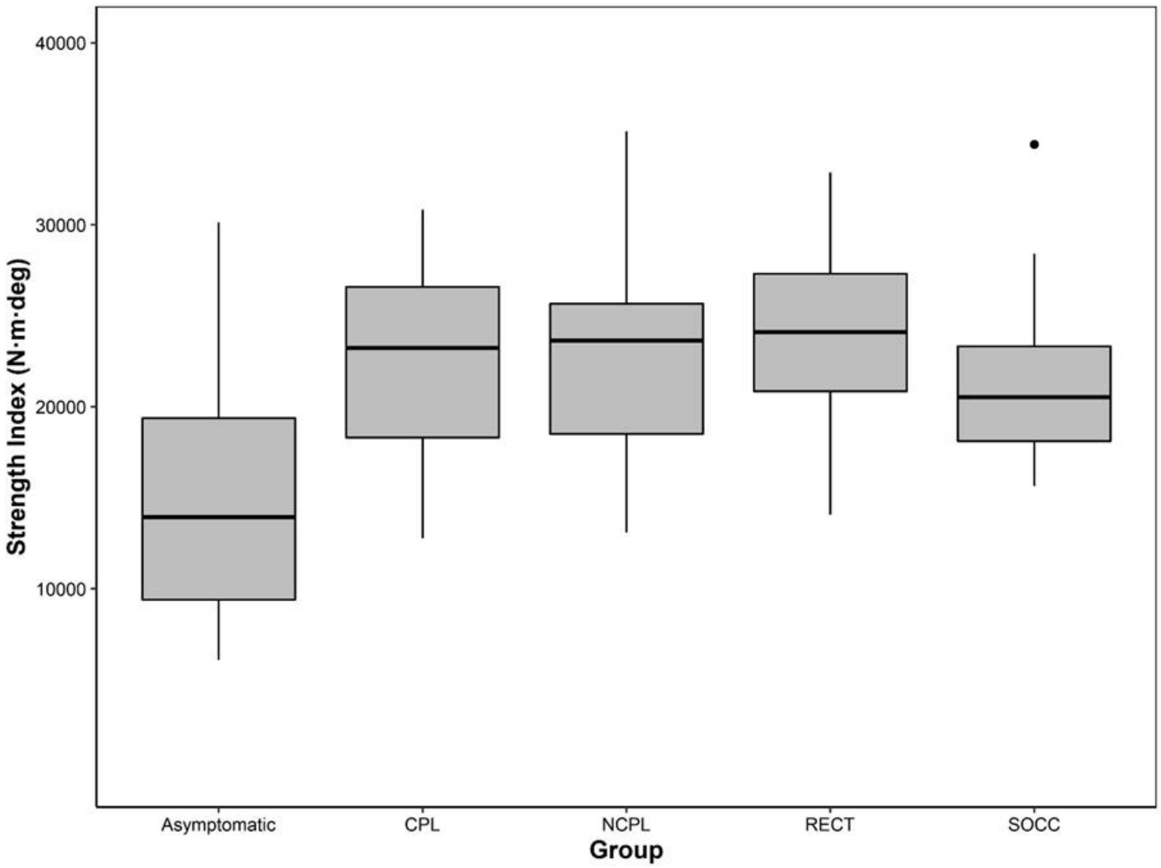


Figure 3: Isolated lumbar extensor SI between populations. CPL: competitive powerlifters; NCPL: non-competitive powerlifters; RECT: recreationally strength trained; SOCC: soccer players

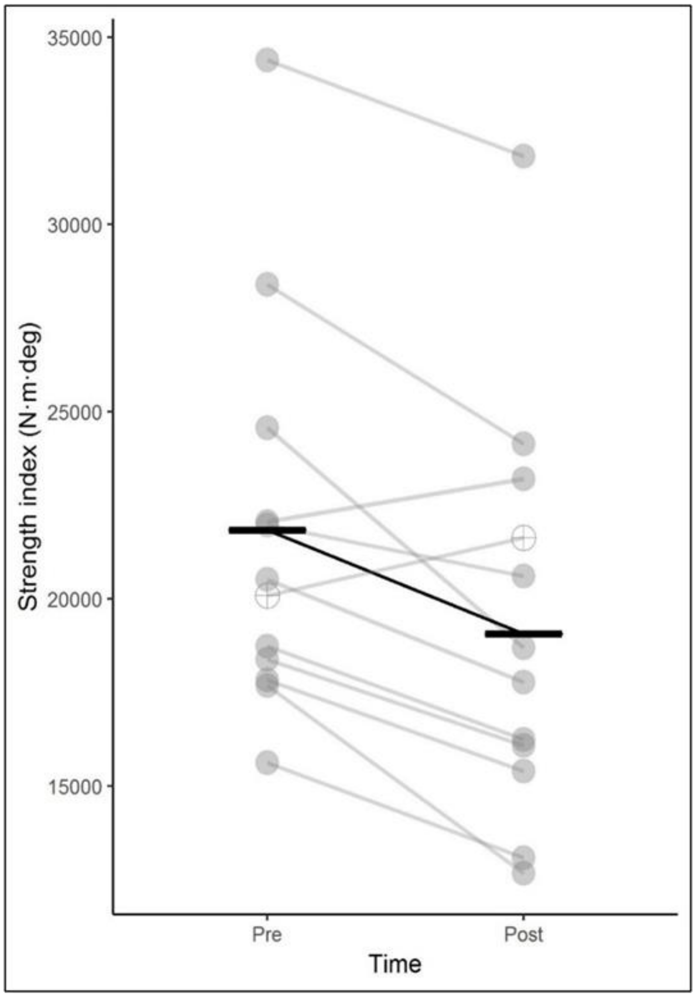


Figure 4: Individual and mean response in SI after the SAFT90 protocol. Note: Bold line represents mean outcome. Open circles represent the excluded outcome.

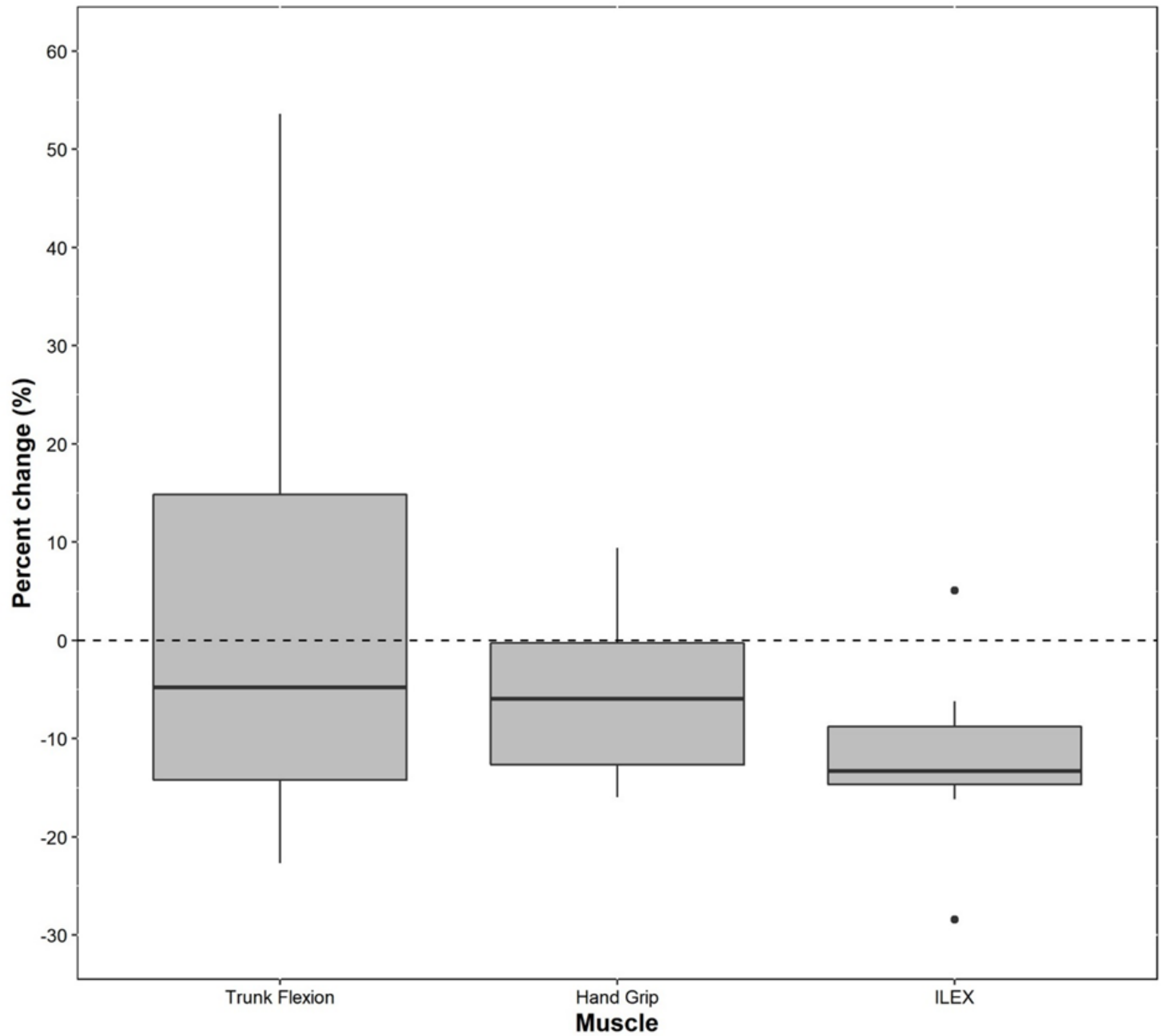


Figure 5: Percentage change for each muscle after the SAFT90. Dashed horizontal line intercepts at 0 as a reference of no change. ILEX: Isolated lumbar extension.

Discussion

This study had multiple aims. The first was to compare maximum ILEX strength between soccer players and non-soccer players. Inferential statistics revealed ILEX strength is greater in soccer players compared to asymptomatic controls from Conway et al. (2018) but is not different to recreationally strength trained participants. Furthering this to populations of powerlifters from Androulakis-Korakakis et al. (2018), it can be seen that their ILEX strength is similar to soccer players (figure 3). The greater ILEX strength in soccer players compared to the asymptomatic group might suggest soccer participation strengthens the lumbar extensors but typical strength-based exercises do not improve ILEX strength (Hammond et al. 2019; Fisher, Bruce-Low and Smith 2013), and that soccer players' ILEX strength is not different to strength trained participants and even competitive powerlifters however, this conclusion seems unlikely. Instead, the findings may reflect a selection bias, where stronger individuals are more likely to engage in sport and resistance training to begin with. The more notable finding is that soccer players, strength trained participants, and powerlifters all possess a similar level of ILEX strength, which suggests an inability to strengthen the muscle without pelvic restraints and is supported by experimental evidence (Hammond et al. 2019; Fisher, Bruce-Low and Smith 2013).

Another aim of this study was to assess whether lumbar extensor fatigue occurs after completing a soccer simulation, and to compare this magnitude to the magnitude of fatigue in the trunk flexors. Indeed, the principal finding from this study is that lumbar extensor fatigue can occur after performing soccer specific movements for 90 minutes. This is the first study to demonstrate that these muscles can be fatigued during sport-specific exercise without pelvic restraints. This has considerable implications for tasks requiring lumbar extensor force, such as maintaining sprint kinematics (Sado, Yoshioka, and Fukashiro, 2016) as without access to equipment capable of strengthening these muscles, athletes might be susceptible to compensations from surrounding muscles leading to an earlier onset of fatigue (Raabe and Chaudhari 2016), changes to kinematics, and reductions in performance. Fatigue in the core muscles has been shown to decrease running time to exhaustion by ~4 minutes (Tong et al. 2014).

It could be argued that the reduction in lumbar force is not a result of mechanical work in these muscles. Supraspinal fatigue resulting from soccer would reduce lumbar extensor force regardless of any potential role in sprinting and movement. Indeed, supraspinal fatigue is evident after both competitive and simulated soccer (~5–10%; Brownstein et al. 2017; Thomas et al. 2017). Despite this, the reduction in SI was greater than the reduction in hand grip strength, suggesting SI reductions were reflective of local fatigue and aligns with a recent meta-analysis that found no evidence of non-local muscle fatigue (Behm et al. 2021).

This study also compared the magnitude of trunk flexion and ILEX fatigue. This study was unable to reject the null hypothesis that the change in trunk flexion endurance time was greater than 0 (i.e. no change). The change in trunk flexion endurance was more varied than in the lumbar extensors (figure 5) but this was largely due to 1 individual recording a 50% increase in trunk flexion endurance time after performing the SAFT90. It's not entirely clear why this was the case, but the participant expressed that they frequently trained the trunk flexors by repeating a similar task. Thus, the individual could have unusually conditioned trunk flexor muscles that were unaffected by the SAFT90. Alternatively, it's possible the participant was more mentally prepared after completing the SAFT90, increasing their motivation withstand fatigue. Despite the greater variability, the median value for the change in trunk flexion is similar to the change in hand grip strength, which suggests the participants who did experience a reduction in trunk flexion endurance did so because of non-local factors. Trunk flexion endurance time in the participants of this study was less than observed in professional soccer players by ~28 s, when using the same test (Abdallah, Mohamed and Hegazy 2019). Whilst professionals may have better trunk flexion strength and endurance, the disparity in findings can also be attributed to the addition of a 5 kg weight and limiting hip flexor involvement in this study, indicating that these measures were effective.

Unlike the trunk flexors, this study found that ILEX strength does reduce after the SAFT90 by 13%. The reduction in ILEX strength was remarkably similar to previous research, where a 12% reduction in lumbar-thoracic extensor torque was found after soccer simulation (Fransson et al. 2018), suggesting that the pelvis was appropriately restrained by Fransson et al. (2018) and adding confidence that the lumbar extensors are fatigued after soccer. Fransson et al. (2018) also found lumbar-thoracic extensor fatigue was greater than in the trunk flexors, which reduced by 10% compared to the 4.5% change observed in this study. This difference could be attributed to the modality of assessment. This study used a measure of trunk flexion endurance due to unavailability of trunk flexion dynamometry whereas Fransson et al. (2018) measured maximum torque. Using a trunk flexion endurance task to measure fatigue has the benefits of requiring little equipment and is easily implemented, but it seems to be less sensitive to changes in the force generating capacity compared to assessments of maximum torque. Nonetheless, taking the findings of this investigation and the findings of Fransson et al. (2018), it can be said with some confidence that lumbar extensor fatigue is greater than the fatigue in the trunk flexors after soccer simulation.

This is particularly important as the lumbar extensors cannot be strengthened optimally without restraining the pelvis (Hammond et al. 2019; Fisher, Bruce-Low and Smith 2013; Bruce-Low et al. 2012) and thus interventions designed to prevent fatigue in these muscles may not be accessible to some. Furthermore, interventions such as the FIFA11+ and those used by Sherry and Best (2004) provide exercises that focus on the anterior trunk muscles and carry the implicit suggestion that the anterior trunk muscles are most important. It is therefore imperative that any risk of injury or performance detriment that could arise from the lumbar extensor fatigue after soccer is established.

There were some limitations with this study. Five minutes of passive rest was allocated between the completion of the simulation and the beginning of strength testing, which would remove the majority, if not all of the metabolic fatigue (Grgic et al. 2018). Periods of high intensity during match play will likely induce greater fatigue. Consequently, it is expected that the true reduction in ILEX strength and trunk flexion endurance is greater during match play compared to the measurements in this study. This delay was necessary to prepare the participants for the ILEX strength and trunk flexion endurance tests.

Conclusion

It has been demonstrated for the first time that the SAFT90 protocol is capable of inducing ILEX fatigue and this is greater than the fatigue experienced in non-local muscles. It therefore seems likely that this will occur in real soccer match play, and possibly to a greater extent if the demands exceed the simulation used in this study. This study failed to demonstrate that trunk flexor fatigue occurs after soccer simulation, and it does not appear to exceed the fatigue measured in non-local muscles after soccer simulation. It has also been shown that the lumbar extensors are unlikely to be strengthened by participating in soccer. It is therefore imperative that the potential consequences of lumbar extensor fatigue from soccer match play are investigated.

Contributions

Contributed to conception and design: CP, JS, DS

Contributed to acquisition of data: CP

Contributed to analysis and interpretation of data: CP, JS

Drafted and/or revised the article: CP, JS, DS

Approved the submitted version for publication: CP, JS, DS

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Data and Supplementary Material Accessibility

This should list the database(s) and, if appropriate, the respective accession numbers and DOIs for all data or supplementary material for the manuscript that has been made publicly available on a trusted digital repository. If no data, code, or supplementary material are available for this manuscript then the reason for this should be explained here.

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