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Replicating lumbar extensor fatigue equivalent to soccer using isolated resistance exercise

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ABSTRACT

Lower lumbar extension strength is associated with back pain and balance, and sufficient force production appears important for maintaining kinematics whilst walking and running. A reduction in lumbar extensor force through deconditioning or fatigue might increase the risk of back pain, falls, and injury. Unfortunately, studies investigating the effects of lumbar extensor fatigue use a magnitude of fatigue which has little ecological validity and does not isolate contributions to the lumbar extensors. We previously showed the lumbar extensors are fatigued more than the trunk flexors after simulating ninety minutes of soccer. Therefore, the purpose of this study was to create a lumbar extensor fatiguing protocol, using a device that immobilises the pelvis, that replicates the lumbar extensor fatigue observed after soccer. Fourteen male amateur soccer players performed a four-repetition and five-repetition isolated lumbar extension protocol using 80% of their peak torque in a randomised counterbalanced design. A z-score of 0.68 about the mean lumbar extensor fatigue after soccer simulation was used to determine the range of equivalence and the five-repetition protocol was found to agree with the fatigue observed after soccer. The four-repetition protocol induced a median reduction that did not fall within the equivalence interval. This protocol can be used to estimate the causal effects of lumbar extensor fatigue from soccer and has the potential to assess players for injury risk and performance potential.

INTRODUCTION

Lumbar extension strength is associated with back pain (Conway et al, 2018) and balance (Behennah et al, 2018), and appears important for maintaining kinematic control during gait including both walking (Steele et al., 2014) and running (Chumanov, Heiderscheit and Thelen, 2007). Whilst it's possible these relationships are confounded by other factors that might correlate with lumbar extension strength, such as mobility and participation in exercise, similar effects appear with experimentally induced transient reductions in lumbar extension force (i.e., fatigue; Hart et al, 2009; Zemkova, Cepkova, Muyor 2021). Unfortunately, studies investigating the effects of lumbar extensor fatigue often do so with a magnitude of fatigue that is arbitrary (Pline et al., 2005; Madigan, Davidson, Nussbaum, 2006; Hart et al., 2009, Lin and Nussbaum et al. 2012) and often the result of performing the experimental task until task failure (Taimela, Kankaanpaa, Luoto, 1999, Hu and Ning 2015; Abboud et al., 2016; Baur et al. 2017; Zemkova, Cepkova, Muyor 2021), which often has little ecological validity to common activities of interest (e.g., sporting activities). These studies demonstrate proof of concept but whether these findings manifest in typical activities is unclear.

In a previous study (Perrin, Smith and Steele, 2022), we found fatigue is greater in the lumbar extensors compared to the trunk flexors after simulating soccer, which we posit could contribute to hamstring injury by increasing forward lean. It is important the causal effects of lumbar extensor fatigue from soccer on hamstring injury risk are understood so that appropriate prevention programmes can be designed, as current interventions such as the FIFA11+ overlook the posterior core muscles (i.e., the lumbar extensors; Sadigursky et al. 2017). In order to ascertain the causal effects of lumbar extensor fatigue in soccer, the consistency assumption must be met (Hernán 2016). This means when examining the effects of lumbar extensor fatigue, the magnitude must be equivalent to that experienced in soccer without causing any other changes. Soccer simulation is clearly an inappropriate method for achieving this as it fatigues multiple muscles (Fransson *et al.* 2018; Greig *et al.* 2008), let alone requiring a time-consuming task (105-minute duration). A commonly used exercise for investigating the effects of lumbar fatigue is the Biering-Sorensen task (Hart *et al.* 2009) but this possesses no association to ILEX torque (r = 0.06; Conway *et al.* 2016). Indeed, Hart *et al.* (2006) reported changes in the hamstring EMG median frequency after the Biering-Sorensen test indicating hip extensor fatigue. Instead, a device that restrains the pelvis such as that used by Bruce-Low *et al.* (2012) is appropriate for isolating the lumbar spine and has been used previously to induce lumbar extensor fatigue, albeit for much larger losses in force compared to that observed in soccer (Stuart *et al.* 2018). Though the ILEX device does limit work to the lumbar extensors, an isometric contraction of the hip extensors still occurs as these muscles attempt to posteriorly rotate the pelvis against the restraint, which may violate the consistency assumption if a meaningful magnitude of fatigue occurred in these muscles. Though EMG studies indicate minimal gluteus maximus activity (~12-15%; Udermann *et al.* 1999) and moderate hamstring activity (31-40%; San Juan *et al.* 2005) with pelvic restraints.

A plethora of studies have investigated the effects of soccer fatigue on injury risk (De Ste Croix *et al.* 2015; Lenhart, Thelen and Heiderscheit 2014; Greig and McNaughton 2014; Small *et al.* 2010— to name a few) but to our knowledge none have attempted to isolate the response of a single muscle or joint for its causal effects. Yet, if effective interventions are to be implemented then an understanding of which muscles should be targeted must be known. Furthermore, a protocol that replicates the lumbar extensor fatigue from soccer can be used as a monitoring tool for clinicians to track changes to interventions and possibly monitor injury risk throughout a season. Similar methods for the lower limbs are used by practitioners (Pinto *et al.* 2017). Therefore, the identification of such a protocol is key to ascertain the causal effects of lumbar extensor fatigue equivalent to soccer match play, and to potentially safeguard athletes from injury and other unknown effects. The purpose of this study was to create a lumbar extensor fatigue protocol, using a device that immobilises the pelvis, that is capable of replicating lumbar extensor fatigue equivalent to soccer.

METHOD

Participants

Fourteen male amateur soccer players were recruited through convenience sampling (age: 20 ± 3 years; mass: 72.9 ± 10.1 kg; stature: 176.1 ± 6.9 cm). Seven players competed in college or university leagues and seven players competed between steps 9–15 (mode of 10) of the English national league system, and all players had outfield positions. Specifically, three were defenders, six were midfielders, and five were attackers. Participants of all sexes were invited but only males volunteered to participate. It is important future research in this area considers female participants as the fatigue response to a given lumbar fatigue protocol appears to differ between sexes (Stuart *et al.* 2018). Participants were excluded if they were currently injured or experiencing any pain or soreness.

Procedure

To replicate the fatigue induced after a simulated football match, a protocol using an isolated lumbar extension (ILEX) device (MedX, Ocala, FL) was designed using the results of Stuart *et al.* (2018). Participants were required to attend the university laboratory on three occasions. First, participants were familiarised with the procedure for testing maximum isometric lumbar extensor strength. The second and third session, each separated by at least 72hrs, both began with a baseline measure of the ILEX strength across the full ROM (0°–72°). Following a ~1-minute passive rest, a dynamic fatiguing task was completed. The aim of this task was to induce a degree of fatigue that approximated the fatigue experienced after simulating soccer (SAFT90 protocol), approximating a reduction in lumbar extension strength index[1] (SI) of 2767 N·m·deg.

[1] Strength index is the area under the isometric peak torque curve, measured across the lumbar range of motion.

The results from the male participants in Stuart *et al.* (2018) were used to estimate the number of repetitions required to induce a similar degree of fatigue by assuming the change in SI was a linear function of time under tension in the high load condition (80% peak torque). This assumption was based on the results of Gorostiaga *et al.* (2012) who found peak power decreased linearly with adenosine triphosphate reduction whereas the reductions in power with lactate followed a non-linear relationship. Thus, the low load condition (50% of peak torque) of Stuart *et al*. (2018) was not included in the estimate due its potential to upwardly bias the estimate of fatigue per repetition.

In the high load condition for males, the time under tension averaged 58 s equating to approximately 8.3 repetitions. Given that the high load condition had a mean reduction in SI of 6167 N·m·deg, the SI change per repetition is estimated to be 743 N·m·deg. Therefore, to achieve the desired reduction in SI of 2767 N·m·deg observed after soccer simulation, approximately 3.7 repetitions, or 4 to the nearest integer, at 80% of peak torque should be performed. However, this is based on fatigue measured immediately post-exercise. For a more practical use of this protocol and to align with the measurement of fatigue after soccer simulation in our previous study, post-exercise torque was measured after five minutes of passive recovery. Thus, additional repetitions may be needed to ensure sufficient fatigue remains after the recovery period. As the magnitude of torque recovery after five minutes is unknown, the precise number of additional repetitions required cannot be calculated.

To identify the optimal prescription of repetitions to replicate soccer equivalent fatigue, participants were tasked with completing two sessions in a randomised order. The 'RANDOM' function in Excel software (version 2016; Microsoft, Reading) was used to assign each participant to a condition. Depending on their condition assignment, participants completed either four or five repetitions in the first session with 80% of their peak torque to induce an estimated SI reduction of 2972 and 3715 N·m·deg respectively. It was anticipated that these values will decrease towards the target value of 2767 N·m·deg after a 5-minute recovery and therefore induce adequate fatigue. Peak torque was considered a practical method for calculating relative loads as the results of Stuart *et al*. (2018) and our own findings show it closely correlates with SI values (r = 0.92–0.93). The second session utilised the same protocol using the remaining scheme of repetitions. In both conditions, the target repetition speed was 7 s (2:1:4 ratio for concentric, isometric and eccentric respectively), though repetition duration increased with fatigue.

Data analysis

Research is yet to investigate the meaningful effects of isolated lumbar extensor fatigue on running kinematics so the required precision of the estimate of lumbar extensor fatigue from the fatiguing protocol was not clear. Teng and Powers (2016) found a positive correlation between hip extensor strength and trunk flexion, where a 2 N·m·kg increase in hip extensor torque correlated with a 1° increase in trunk flexion (*r* = 0.55). Using this as an anchor for our estimate, the change in the lumbar extensor SI to produce a 1° change in trunk lean would be 7488 N·m·deg. This reduction in SI is calculated using the trapezoidal estimate of the integral (4), where x is lumbar extensor torque, with peak torque equal to 140 N·m (2 N·m·kg where sample mass is 70 kg) and produced at full flexion (72°), decreasing linearly to 70 N·m at full extension with a ratio of 2:1 (ratio obtained from raw data of Stuart *et al*. 2018).

$$\int_{0°}^{72°} f(x) d12° \qquad (4)$$

However, a change in SI of 7488 N·m·deg is excessive for the lumbar extensors as the raw data of Stuart *et al.* (2018) show that performing repetitions of isolated lumbar extension to task failure reduces SI by 6167 and 9119 N·m·deg for high loads and light loads respectively. This estimates that to produce a 1° change in trunk flexion the lumbar extensors must act to volitional failure. This seems unrealistic and so the hip extensors are unlikely to be representative of the lumbar extensors. In circumstances where precision cannot be deduced, arbitrary recommendations such as an effect size of 0.2 have been suggested (Cook *et al.* 2018; Hislop *et al.* 2014). This effect size recommendation is a conservative estimate in the dearth of a-priori knowledge, but here the desired distribution of data is known. Thus, the agreement of the protocol was estimated based on the results of lumbar extensor fatigue after soccer simulation using a Z-score approach. The Z−score was preferred as *t* scores provide intervals for the mean statistic and not the proportion of data about the mean. Likewise, with small samples, *t* statistics can provide a broad range of values reflecting the uncertainty and this would lead to low power to detect similarity as a range of values could fit the interval.

Statistical analysis

A z-score of 0.68 about the mean lumbar extensor fatigue after soccer simulation was used to determine the range of equivalence. This score was chosen as it is equivalent to ± 25%

of the population about the mean, assuming a perfectly normal distribution, and therefore reflects the majority of the population responses with regards to soccer induced ILEX fatigue. The population SD of lumbar extensor fatigue after soccer simulation was estimated using a sample standard deviation with n−1 degrees of freedom. A z score of 0.68 ± the mean fatigue produced from the soccer simulation produced an SI interval of −1502 to −4032 N·m·deg. The fatiguing protocol was deemed to agree with soccer induced fatigue when the upper and lower bound of the 90% CI did not overlap with −1502 and −4032 N·m·deg respectively. A 90% CI was chosen as this is analogous to two, one-sided t-tests used in equivalence testing. Statistical analyses were performed using SPSS (Version 25; IBM Corp. 2019).

Results

Following a Shapiro-Wilks test for the assumption of normality, it was revealed data for the four-rep protocol supported rejection of this assumption (W = 0.745; df = 14; p = 0.01) but change scores for the five-repetition protocol was (W = 0.971; df = 14; p = 0.886). Descriptive statistics showed the four-rep protocol induced a median of −1009 N·m·deg (interquartile range: 1497 N·m·deg) whereas the five-rep protocol induced a mean change of −2686 ± 1703 N·m·deg. It was subsequently decided to not further test the 4-rep protocol due to the median value being outside of the acceptable range (−1502 and −4032 N·m·deg) and therefore of insufficient force loss. The 90% CIs for force loss after five repetitions was −1880 to −3492 N·m·deg and within the acceptable interval (−1502 and −4032 N·m·deg).

Discussion

The aim of this study was to identify a protocol capable of inducing lumbar extensor fatigue with a magnitude equivalent to that experienced in soccer. It has been shown that a five-repetition protocol with a load of 80% of peak torque is capable of achieving such requirements. This is the first study to induce fatigue that is specific to the lumbar extensors while achieving a magnitude of fatigue equivalent to a sporting context and offers a viable approach for investigating causal effects, and for assessing the effectiveness of training protocols and player monitoring.

The addition of one repetition from four to five had an effect that was surprising. The force reduction between four and five repetitions was −1677, 60% of the fatigue induced from soccer simulation. This is unexpected given the lumbar extensors are primarily type one fibres (Cagnie et al. 2015). The lumbar extensors are clearly sensitive to relatively small changes in intensity of effort (i.e., proximity to momentary failure) and raises the question as to whether the fatigue response approximates a step function, where a threshold of physiological work leads to large increases in torque loss (fatigue). It would be interesting to assess if lumbar extensor fatigue is present at half-time as Woods et al. (2004) identified the final third of both halves in soccer poses an increased HSI risk. Furthermore, the fact a single set of five repetitions at 80% of peak torque is sufficient to induce the same fatigue experienced in soccer may have implications for the scheduling of lumbar extensor testing and training. Practitioners should be careful not to implement lumbar extensor testing or training prior to physical activity as this may impair performance or worse, leave them susceptible to injury. Indeed, there is evidence lumbar extensor fatigue changes the co-ordination between pelvis and lumbar spine during weightlifting, which is thought to increase the risk of back injury (Hu and Ning 2015). Future research would benefit by understanding the time to recover the loss in lumbar extensor torque from soccer match play.

Some limitations are acknowledged with this procedure. The repeated measures design means this study is susceptible to demand characteristics, but the two levels of study mitigate potential problems as participants were unaware which protocol was thought to be more successful, nor were they aware of the desired fatigue from the protocols nor able to monitor except via interoception which would be unlikely valid enough to rely upon. Therefore, it seems unlikely demand characteristics explain these findings. The mechanism of inducing lumbar extensor fatigue is likely different to that in soccer, where fatigue accumulates from 90 minutes of match play compared to the five repetitions of weighted lumbar extension used here. Despite this, it is the reduction in force that is of primary importance, as this is responsible for maintaining kinematics, not the underpinning cause of this magnitude of fatigue per se. Because of the sensitivity of the lumbar extensors to one additional repetition, future work would benefit by examining the effects of parameters such as load to achieve a more precise estimate of fatigue (i.e., using lighter loads enabling a wider range of repetitions to be explored).

Conclusion

The results of this study have shown that lumbar extensor fatigue induced by soccer simulation can be replicated in isolation and with reasonable precision by performing five repetitions at 80% of peak torque. The development of this protocol can be used to assess training adaptations in soccer players, and more importantly the causal effects of soccer equivalent lumbar extensor fatigue can be assessed while minimising confounding from synergistic muscles. If this protocol is shown to increase injury risk or impair performance, this protocol may well serve as a predictive tool for assessing injury risk or performance potential.

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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