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The cumulative and residual changes in eccentric knee flexor strength indices following soccer-specific treadmill running: novel considerations of angle specific torque.

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Running head:

The cumulative and residual knee flexor fatigue response to soccer-specific exercise.

Key words:

Torque, Intermittent, Recovery

Abstract

With potential implications for recovery and conditioning practices, the aim of this study was to assess the cumulative and residual response of angle specific eccentric knee flexor (eccKF) strength indices following soccer-specific activity. Thirteen semi-professional soccer players were therefore required to complete a 90-minute soccer-specific treadmill running. with eccKF isokinetic strength assessments completed pre-trial, immediately post-trial, and 48 hours post-trial. The strength assessments comprised the completion of 5 repetitions at angular velocities of 60 and 300 $deg \cdot s^{-1}$. Isokinetic data was analysed for measures of peak torque (PT), angle of peak torque (APT), functional range (FR), and angle specific torque (AST). Significant post-trial impairments were observed for measures of slow velocity PT_{60} (6.6%) and AST_{300} (12.5%). Further significant differences were observed 48 hours post-trial for PT_{300} (10.7%) and PT_{60} (12.8%) PT, APT_{60} (~15°), and AST_{300} (>13.6%). These data have implications for post exercise recovery monitoring and the prescription of recovery modalities and conditioning practices in the 2 days following match-play. The AST and APT responses highlight the importance of analysis of the entire strength-angle curve and at a range of angular velocities.

Introduction

The primary extrinsic risk factors associated with soccer injuries have been identified as congested match scheduling and a subsequent inability to fully recover between matches (McCall et al., 2015). Fatigue is a key risk factor for injury in intermittent team sports (Ekstrand, Hägglund, &Waldén, 2011), and it has been reported that a 2-day period (worst case scenario between matches) is not sufficient to allow for full recovery (Ispirlidis et al., 2009; Magalhäes et al., 2010). It is therefore important to assess markers of fatigue and injury risk during and between successive matches, especially during periods of fixture congestion where limited recovery is provided between matches.

The most prevalent injuries during intense fixture schedules are thigh-based strains (Dellal, Lago-Peñas, Rey, Chamari, & Orhant, 2015), with the knee flexor musculature being most commonly injured (Dupont, et al., 2011). Isokinetic dynamometer-based strength assessments have previously been utilised to identify fatigue-induced changes in strength following the completion of single (Rahnama, Reilly, & Lees., 2003; Greig, McNaughton, & Lovell, 2006; Marshall, Lovell, Jeppesen, Andersen, & Siegler, 2014; Rae, Stephenson, & Roden, 2015) and repeated bouts of soccer-specific activity (Chen & Nosaka, 2006; Cobley, McGlory, Morton, & Close, 2011; Page et al., 2018).

However, to date, literature has identified a limited association between injury incidence and the commonly utilised isokinetic indices of strength (Bennell et al., 1998; Sharir et al., 2016; Van Dyk et al., 2016; Van Dyk et al., 2017). This lack of association might be attributed to the choice of analysis metrics, with the reduction of a continuous torque-angle curve to a single value of peak torque (Baumgart et al., 2018; Eustace et al., 2017).

This peak value negates an understanding of the torque-angle relationship, and interpretation across the angular range associated with functional movement. Further limitations in previous attempts to relate isokinetic dynamometry to injury risk are evident in a potentially restrictive selection of testing speeds (Van Dyk et al., 2017), failing to match the functional challenge and mechanism of injury. For example, knee angular velocities of ~400 $deg \cdot s^{-1}$ have been identified during tasks associated with injury risk in soccer (Nedergaard, Kerstin, and Lake, 2014). The ability to test at such angular velocities is restricted by the capabilities of IKD and the ability to obtain an isokinetic phase; however, these dynamometers do allow for testing speeds up to 300 $deg \cdot s^{-1}$, thus increasing the functional relevance of testing beyond the velocities that are commonly used.

Contemporary analyses include metrics such as functional range (FR), which quantifies the angular range over which a predetermined threshold of isokinetic strength can be maintained (Eustace et al., 2017). The FR metric has however only previously been utilised to make descriptive comparisons between youth and adult soccer players (Eustace et al., 2018a), with no appreciation as to how this metric may differ as a result of fatigue. Angle-specific measures of torque (AST) have also been advocated (Boden and Dean., 2000; Chumanov, Schache, Heiderscheit and Thelan., 2012). Angle specific measures of isokinetic strength have recently been applied to an evaluation of playing level (Cohen et al., 2015; El-Ashker et al., 2015; Evangelidis et al., 2015), playing age (Eustace et al., 2018a), and the influence of previous injury (Eustace et al., 2018b). Cohen et al. (2015) considered angle-specific torque changes immediately following soccer-specific fatigue, but to date the literature has failed to consider the impact of fixture congestion on eccentric hamstring strength metrics that consider the strength curve across a range of velocities. Angle specific strength assessments across a range of angular velocities will more fully inform recovery and injury prevention strategies, supporting recent calls that AST data should be conducted in a more specific and meaningful manner (Duarte et al., 2018).

Quantifying the physical response to soccer-specific activity using actual match-play (Ispirlidis et al., 2009; Rampinini et al., 2011; Mohr et al., 2015) offers high ecological validity, but is constrained in terms of data collection (Stølen, Chamari, Castagna, and Wisløff., 2005; Rollo, Impellizzeri, Zago, and Laia., 2014) and that matches are susceptible to contextual factors (Rollo et al., 2014). The use of valid soccer-specific exercise protocols (SSEPs) have therefore been advocated as a potential method of mechanistically assessing the cumulative and residual physical response to soccer-specific activity (Carling et al., 2015). However, previous applications of SSEPs to the temporal pattern of recovery (Page et al., 2017; Rhodes, McNaughton, and Greig., 2018) have only considered the maxima of the eccentric hamstring torque-angle curve.

With implications for recovery strategies and training prescription, the aim of this study was to assess isokinetic eccentric knee flexor (eccKF) strength characteristics of male football players immediately following, and two days after, the completion of a SSEP.

Method

Participants

Thirteen semi-professional soccer players (age 24.8 ± 4.4 years; height 181.1 ± 4.7 cm; mass 80. 6 ± 5.0 kg) were recruited from the same club in the fifth tier of the English

Football League system. Inclusion criteria specified that all participants were outfield players, were apparently healthy, and were injury free for >6 months prior to data collection. In addition to weekly matches, the participants completed typical weekly training volumes of > 6h·week^{-1}. Prior to each experimental condition, all participants were required to complete a health screening procedure comprising a health, physical activity and pre-exercise control questionnaire. The measurement of both resting heart rate and blood pressure was also measures, where resting heart rate >90 beats·min^{-1} and blood pressure >140/90 mmHg respectively were contraindications to exercise. All participants were informed of the risks associated with the study before providing written consent. The current study was also approved by a local university ethics committee. All equipment was risk assessed and calibrated in accordance to the manufacturer's guidelines.

Experimental Procedures

Participants were required to attend the laboratory on three occasions to complete a familiarisation trial, an experimental trial, and an IKD based follow up assessment completed 48hrs after the experimental trial. A minimum of 96 hours interspersed the familiarisation trial and the experimental trial. The familiarisation trial comprised 2 x 15 min bouts of the SSEP (Page et al., 2015) used in the experimental trials, and an Isokinetic dynamometer protocol (comprising all testing speeds) completed pre- and post-trial which informed subsequent angular range in experimental trials. The experimental trial comprised the completion of a 90-minute treadmill-based (H/P/Cosmos Pulsar 4.0, H/P/Cosmos Sports and Medical GmbH, Germany) SSEP (Page et al., 2015; 2016). The

SSEP comprised 6 x 15 min bouts of standardised intermittent activity, with a 15min passive recovery period between the third and fourth bouts to represent half-time (HT). The velocity profile of the SSEP (Figure 1) was based on notational analysis of match-play (Mohr et al., 2003) and conducted with varying levels of gradient (Jones and Doust., 1996). The velocity profile was designed to replicate the clusters of high intensity activity interspersed with periods of low intensity passive and activity recovery as observed during match-play (Spencer et al., 2004; Barnes et al., 2014).

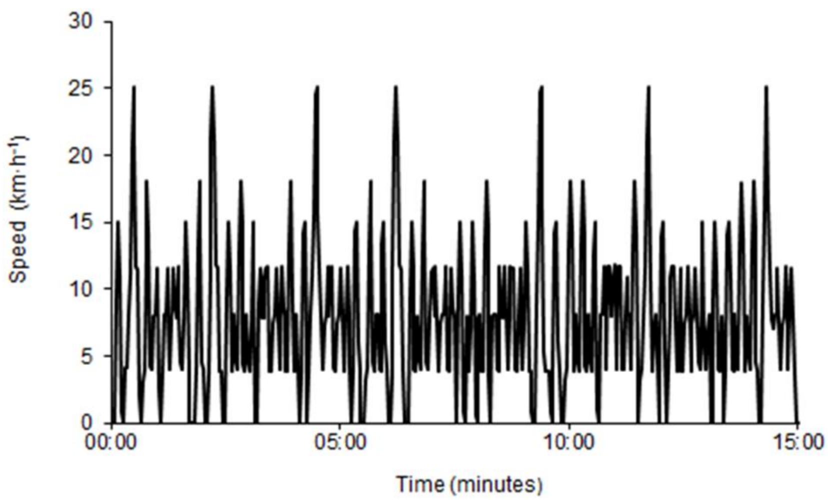

Figure 1: Schematic representation of a single 15min bout of the SSEP and the data upon which it is based.

In an attempt to control for circadian variation (Rae, Stephenson, and Roden 2015), all experimental trials and follow up assessments were completed in accordance with the participants regular training times (between 1700 and 2000 hours). All SSEP trials were conducted in an ambient controlled environmental chamber with temperature and humidity maintained at 21 ± 0.5 °C and 35 ± 1.5 % respectively. Participants were required to attend the laboratory on each occasion in a 3h post-absorptive state following a 48h period of abstinence from exercise, alcohol, and the use of recovery strategies. Prior to the start of the SSEP, participants were required to complete a standardised treadmill based intermittent warm-up followed by a period of self-directed dynamic stretching. The warm-up comprised the progressive completion of the running speeds associated with the SSEP and was designed to replicate the intensities, durations, and distributions of speed changes associated with a pre-match warm up routine (Greig et al., 2006).

Experimental measures

Eccentric knee flexor strength characteristics were recorded pre-, post-, and 48hr post-trial using an isokinetic dynamometer (System 4, Biodex Medical Systems, Shirley, New York, USA) at speeds of 300 and 60 $deg \cdot s^{-1}$ (5.25 and 1.05 $rad \cdot s^{-1}$). The order of the speeds was standardised across trials (Greig., 2008). The range of motion of the knee joint was set at 95–25° of knee flexion. Participants were instructed to complete 5 maximal dominant leg (preferred kicking leg) contractions at each speed. The leg that the athlete preferred to kick the ball with or that they could kick the ball the farthest with was noted as the preferred kicking leg (Brown, Brughelli, and Bridgeman 2016) A 60 second rest period was provided between each angular velocity (Croisier et al., 2008), with no performance feedback provided (Campenella et al., 2000). Each participant was secured in a seated position with approximately 90º hip flexion, with restraints applied proximal to the knee joint across the thigh, the waist, and the participant's chest, with the cuff of the lever arm secured 3cm proximal to the malleoli. As per the manufacturer's guidelines, torque was gravity-corrected following the measurement of the participant's limb mass performed in a position of full knee extension, with the system software correcting for the angular error from horizontal. During each rep the limb weight contribution is calculated as the torque from the limb multiplied by the sin(angle). When considering the upward movement of the limb for eccKF contractions, and therefore the limb is working against gravity), the gravity correction is added to the participant's torque. In an attempt to minimise the influence of both the gender (Winchester et al., 2012) and the number (Rhea, Landers, Alvar, and Arent., 2003) of observers, only one male researcher and the participant were present during the completion of the experimental trials.

Data analyses

The isokinetic phase was identified at the constant angular velocity by applying a 1% cut-off (Eustace et al., 2017), with analysis applied to the repetition eliciting the highest peak torque (PT). The PT and corresponding angle of peak torque (APT) were identified as the highest torque value within the chosen repetition, and the angle at which this occurred. The functional range (FR) was defined as the angular range over which 85% of PT was maintained (Eustace et al., 2017). In addition, the extremes of FR were identified at the extended (FR_{EXT}) and flexed (FR_{FLEX}) positions to further inform the location of FR within the strength curve. Angle specific torque (AST) values were also identified at 5° increments between 60 and 40° for the 300 $deg\cdot s^{-1}$ data and 65-30° for the 60 $deg\cdot s^{-1}$ data. These angular ranges were chosen as the isokinetic phases common to all participants across measurement points. The reduced angular range for the fast velocity data was due to the inherent smaller isokinetic phase because of the acceleration and deceleration of the dynamometer. Likewise, although the participants were able to generate an increased isokinetic range for both velocities pre-trial, this was not able to be maintained post-trial, and 48h post-trial, thus limiting our analysis to the common range. In subsequent sections these parameters are annotated according to angular velocity so, for example, peak torque recorded at $60°\cdot s^{-1}$ is labelled as PT_{60}.

Statistical analyses

Inferential analyses were performed using a repeated measure general linear model (GLM) to examine differences in the isokinetic data recorded between measurement points. The assumptions associated with the GLM were assessed to ensure model adequacy. With the exception of Mauchly's test of sphericity, the current data did not violate any of the assumptions, and therefore inferential analyses were performed. Normality was assessed via the assessment of the Shapiro-Wilk test using the stacked standardised residuals. Outliers were assessed as any standardised residuals that were greater than 3 SD away from the mean. Where sphericity was not assumed, a Greenhouse Geisser correction was applied. Furthermore, where significant main effects or interactions were observed, post hoc pairwise comparisons with a Bonferonni correction factor were applied. For all significant main effects and interactions, 95% confidence intervals (CI) for differences are also presented. Partial eta squared (η^2) values were calculated to estimate effect sizes for all significant main effects and interactions. Partial eta squared was classified as small (0.01 to 0.059), moderate (0.06 to 0.137), and large (>0.138). All statistical analysis was completed using PASW Statistics Editor 25.0 for windows (SPSS Inc, Chicago, USA). Statistical significance was set at $P \leq 0.05$. All data is reported as mean ± SD unless otherwise stated.

Results

Peak torque and Angle of Peak torque

As identified in table 1, the repeated measures general linear model (GLM) identified a significant main effect for time associated with the PT_{60} ($P< 0.001$; $\eta^2= 0.486$), PT_{300} ($P= 0.018$; $\eta^2= 0.285$), APT_{60} ($P= 0.023$; $\eta^2= 0.331$) data. The GLM did not however identify a significant main effect for time ($P= 0.313$; $\eta^2= 0.092$) for the APT_{300} data.

Table 1: The PT and APT data recorded across measurement points. * denotes a significant difference with pre-trial.

	Measurement point		
Metric	Pre-trial	Post-trial	48 hrs post-trial
PT_{60} (Nm)	158.1 ± 33.4	147.7 ± 33.5*	138.0 ± 25.5*
		95% CI: -18.0 to -2.8	95% CI: -33.2 to -7.1
PT_{300} (Nm)	160.1 ± 20.4	149.2 ± 26.7	143.0 ± 15.8*
			95% CI: -31.6 to -2.7
APT_{60} (°)	32 ± 9	36 ± 13	47 ± 24*
			95% CI: 1 to 31
APT_{300} (°)	46 ± 14	48 ± 14	51 ± 14

Functional range metrics

As identified in table 2, the GLM did not identify significant main effects for time for FR_{300} (P= 0.074; η^2= 0.195), FR_{60} (P= 0.872; η^2= 0.011), $FR_{FLEX300}$ (P= 0.363; η^2= 0.076) FR_{FLEX60} (P= 0.154; η^2= 0.155), FR_{EXT300} (P= 0.598; η^2= 0.042), or FR_{EXT60} (P= 0.534; η^2= 0.051).

Table 2: The FR metrics recorded across measurement points.

	Measurement point		
Metric	Pre-trial	Post-trial	48 hrs post-trial
FR_{60} (°)	41 ± 13	34 ± 10	44 ± 16
FR_{300} (°)	16 ± 13	15 ± 9	15 ± 10
FR_{FLEX60} (°)	63 ± 11	60 ± 13	69 ± 20
$FR_{FLEX300}$ (°)	57 ± 12	55 ± 8	58 ± 7
FR_{EXT60} (°)	24 ± 5	26 ± 10	25 ± 7
FR_{EXT300} (°)	42 ± 14	40 ± 12	43 ± 14

Angle specific torque

As identified in figure 2, the GLM identified a significant interaction between time and angle (P< 0.001; η^2= 0.327), with pairwise comparisons identifying significantly higher AST_{300} data recorded at 50° (141.0 ± 22.9 Nm; 95% CI= 4.3 to 33.2 Nm), 45° (147.0 ± 23.9 Nm; 95% CI= 11.6 to 43.5 Nm), and 40° (150.4 ± 19.4 Nm; 95% CI= 13.5 to 44.1

Nm) pre-trial, when compared to the corresponding data 48hrs post-trial (50°= 121.8 ± 18.1 Nm; 45°= 119.5 ± 25.1 Nm; 40°= 121.7 ± 24.4 Nm). Significantly higher values were also recorded pre-trial at 40° when compared to the corresponding data post-trial (131.6 ± 33.3 Nm; 95% CI= 1.8 to 36.0 Nm). The GLM also identified a significant main effect for time (P= 0.001; η^2= 0.441), with significantly higher values recorded pre-trial when compared to both post-trial and 48hrs post-trial. There was not however a significant main effect for angle (P= 0.513; η^2= 0.053).

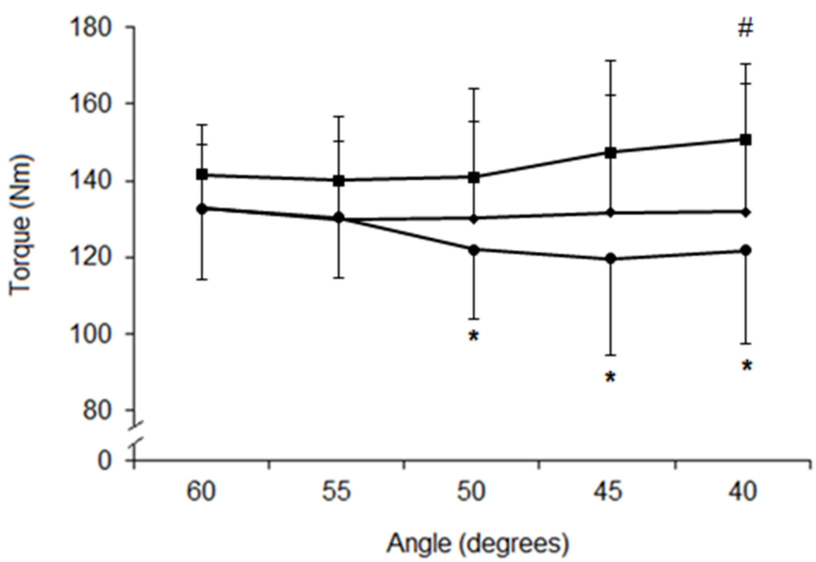

Figure 2: The AST_{300} data recorded pre-trial (■), post-trial (♦), and 48hrs post-trial (●). Error bars have been removed from the post-trial data to aid clarity. * and # denote significant differences with the corresponding data recorded pre- and post-trial respectively.

As identified in figure 3, the GLM did not identify a significant time and angle interaction (P= 0.049; η^2= 0.899) for the AST_{60} data, with pairwise comparisons identifying significantly higher AST_{60} data recorded pre-trial at 65° (129.4 ± 24.0 Nm; 95% CI= 3.9 to 25.3 Nm), 60° (135.4 ± 24.7 Nm; 95% CI= 7.8 to 28.0 Nm), 55° (140.3 ± 24.8 Nm; 95% CI= 3.9 to 25.3 Nm), 50° (143.4 ± 25.8 Nm; 95% CI= 13.4 to 31.6 Nm), 45° (146.3 ± 26.9 Nm; 95% CI= 13.5 to 32.5 Nm), 40° (148.4 ± 28.0 Nm; 95% CI= 12.4 to 32.4 Nm), 35° (150.9 ± 29.7 Nm; 95% CI= 11.5 to 33.7 Nm), and 30° (150.1 ± 34.1 Nm; 95% CI= 6.8 to 28.5 Nm) when compared to 48 hrs post-trial (65°= 114.8 ± 11.4 Nm; 60°= 117.5 ± 13.7 Nm; 55°= 119.6 ± 15.1 Nm; 50°= 120.9 ± 18.3 Nm; 45°= 123.2 ± 21.1 Nm; 40°= 126.0 ± 24.5 Nm; 35°= 128.3 ± 27.2 Nm; 30°= 128.5 ± 30.1 Nm).

Higher values were also recorded pre-trial at 55° (95% CI= 2.4 to 16.2 Nm), 50° (95% CI= 3.3 to 15.2 Nm), 45° (95% CI= 5.0 to 19.5 Nm), 40° (95% CI= 4.6 to 25.4 Nm), 35° (95% CI= 6.5 to 28.7 Nm), and 30° (95% CI= 6.8 to 28.5 Nm) when compared to post-trial (55°= 131.0 ± 28.0 Nm; 50°= 134.1 ± 29.1 Nm; 45°= 134.0 ± 32.0 Nm; 40°= 133.4 ± 36.2 Nm; 35°= 133.3 ± 40.9 Nm; 30°= 132.4 ± 44.1 Nm). Significantly higher values were also recorded post-trial at 55° (95% CI= 0.8 to 22.1 Nm) and 50° (95% CI= 2.5 to 24.0 Nm) when compared to 48 hrs post-trial.

The GLM also identified a significant main effect for time (P= 0.001; η^2= 0.497), with significantly higher values recorded pre- trial when compared to both post-trial and 48hr post-trial. The GLM also identified a significant main effect for angle (P= 0.043; η^2= 0.290).

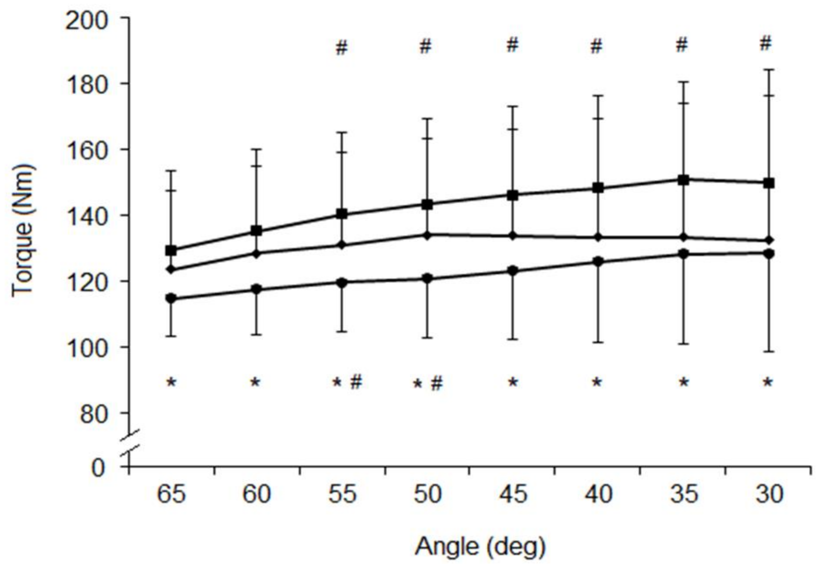

Figure 3: The AST_{60} data recorded pre-trial (■), post-trial (♦), and 48hrs post-trial (●). Error bars have been removed from the post-trial data to aid clarity. * and # denote significant differences with the corresponding data recorded pre- and post-trial respectively.

Discussion

The aim of the current study was to assess isokinetic eccentric knee flexor (eccKF) strength characteristics of male football players both immediately following, and two days after the completion of a SSEP. Significant post-trial impairments were observed for PT_{60} and AST_{300} at 40^{o} of knee flexion. Further significant differences were observed 48 hours post-trial for measures of PT_{60} and PT^{300}, APT_{60}, and AST_{300} over an extended range of 40-50^{o}.

In relation to the commonly reported metrics of PT, a significant difference was observed between the pre-trial PT_{300} measures (160.1 ± 20.4 Nm) and the data recorded 48 hours post (143.0 ± 15.8 Nm; 10.7%). There were however no significant differences observed immediately post SSEP (149.2 ± 26.7 Nm; 6.8%) when compared to the other measurement points. With regards to the slow velocity data, both the post-trial (147.7 ± 33.5 Nm; 6.6%) and 48 hours post-trial (138.0 ± 25.5 Nm; 12.8%) data was lower than that recorded at rest (158.1 ± 33.4 Nm). Although not significantly different for the PT_{300} data, the relative cumulative fatigue response is similar across angular velocities. There is however a greater residual reduction observed for the slow velocity PT. The current PT data therefore supports previous literature which has assessed PT immediately post prolonged soccer-specific activity (Rahnama, Reilly, Lees, and Graham-Smith, 2003; Greig et al., 2006; Greig 2008; Small et al., 2009; Marshall, Lovell, Jeppesen, Anderson, Siegler, 2014; Wollin, Thorborg, and Pizzari, 2017; Rhodes et al., 2018) and those studies which have attempted to track this response in the days following (Page et al., 2018; Rhodes et al., 2018; Wollin, Thorborg, and Pizzari 2018). The observed differences in the current PT data whereby the magnitude of the residual fatigue response appears to be velocity dependent, therefore further reiterates the torque velocity relationship, and the need to monitor strength across a range of angular velocities. The increased residual reduction in slow speed PT may be associated with the sequential recruitment of muscle fibres with regards to force generation, whereby the slow twitch muscle fibres are more regularly recruited during the SSEP (Eston et al., 2003). However, as previously discussed within the introduction, this PT metric only considers a single point on the strength curve, negating an understanding of the sensitivity of strength to changes in angle, or how strength is maintained over the predetermined angular range.

Angle of peak torque is often considered in unison with PT as a method of better coupling the relationship between torque and angle. The current APT data identified a temporal response for both the fast (~6°) and slow (~15°) velocity assessments whereby there was a fatigue-induced shift in the angle towards a more flexed position over the 48-hour post-trial period. In support of previous literature (Rhodes et al., 2018) and also the observations made with regards to the current PT data, these data therefore suggest that the cumulative fatigue response in APT is velocity dependent, thus further advocating the need to conduct isokinetic assessments across a range of velocities. When considering that PT is significantly reduced 48 hours post-trial, the current APT data suggests that there may also be a potentially exacerbated reduction in torque in more extended positions, with implications for potential injury risk. A similar response has also been observed in participants with previous hamstring strain injuries (Brockett, Morgan, and Proske 2004), with a 12° change in APT towards a more flexed position being observed in a previously injured limb when compared to the non-injured ipsilateral limb. As previously discussed, the consideration of PT and the angle at which this occurs does not however allow for the consideration of strength throughout the range of motion.

The previously defined functional range (FR) metric has been advocated to further advance the single point measures of PT and APT, and instead, provide a method to better consider the torque-angle curve. Previously the FR metric has been used to provide an angular range over which a specific threshold of strength (85% of peak torque) can be maintained, with a strength deficit of 15% is associated with an increased risk of thigh musculature injuries in professional male soccer players (Croiser, Ganteaume, Binet, Genty, and Ferret 2008). The FR metric has also not previously been considered in relation to cumulative and residual fatigue. The current FR data recorded at both angular velocities was shown to not be significantly different across measurement points, with the slow velocity data being maintained between ~65° and ~25° of knee flexion and the fast velocity data between ~57° and 42°. These data therefore suggest that the ability to maintain 85% of PT does not appear to be influenced by prolonged soccer-specific treadmill running, thus suggesting that although there is an observed reduction in PT, thus reducing the peak of the torque angle curve, the shape of the curve is somewhat maintained.

The differences in the FR data recorded from the slow and fast angular velocities suggests that the participants are able to maintain slow speed torque over a greater angular range when compared to the fast velocity torque. The observed lack of a cumulative and residual fatigue response associated with the FR metric does raise potential questions about the use of this metric for monitoring post-exercise recovery; however, the data does still have implications for conditioning practices whereby training should be prescribed at fast angular velocities at knee flexion angles where we know large strength deficits exist. The total FR recorded at fast (~15°) and slow (~40°) angular velocities is different at both velocities when compared previous studies that have reported FR data in adult soccer players (Eustace et al., 2017), with increased FR being observed by Eustace and colleagues at fast angular velocities and reduced FR at slow angular velocities. The current data is however like youth players, who as like our semi-professional cohort, would possess impaired strength characteristics when compared to full-time professional adult players (Eustace et al., 2018a).

The current marked reduction in FR at high angular velocities also contradicts the observation made in full-time professional adult players, who were able to elicit similar

FR at both slow and high velocities. The comparisons made with both youth and full-time adult players therefore suggests that the FR metric is modifiable through chronic exposure to soccer-specific conditioning. Previous literature (Eustace et al., 2018b) has also identified that the torque-angle curve can be modified greater than the SEM from a more acute exposure (6 week) to a targeted training intervention. Indeed, although the FR allows for the identification of a player's ability to maintain strength across an angular range, it does not identify if any change in the torque angle has resulted in an impairment towards a more flexed or extended position. An improved consideration has therefore been made in the current study to consider the specific knee angle at which the participant was unable to maintain 85% of their PT into both flexion and extension. The use of FR metrics allows for an easily administered and applied analysis of the torque angle relationship, but these metrics lack the ability to consider both the amplitude and the shape of the torque angle curve that is achievable from analysis methods such as statistical parametric mapping.

To further advance the notion of better assessing the torque-angle relationship of the KF musculature, without the need for advance statistical analysis, the current study comprised the assessment of AST. This metric was calculated across 5° increments between 60° and 40° of knee flexion for the fast velocity data and between 65° and 30° of knee flexion for the slow velocity data. The angular range associated with the fast velocity data was chosen based on both previous literature (Eustace et al., 2017; 2018a) and the notion that this range was common across measurement points. It should be acknowledged that the increased isokinetic range associated with the slow angular velocity contractions allows for an increased number of AST increments to be included. The current data identified that the fast velocity angle specific torque data was significantly impaired at 50° (19.2Nm; 13.6%), 45° (27.5 Nm; 18.8%), and 40° (28.7 Nm; 19.1%) pre-trial when compared to the corresponding data 48 hours post-trial. Significantly lower torque values were observed at 40 degrees post-trial when compared to the corresponding measure pre-trial (18.8 Nm; 12.5%). Although not measured beyond the 60-40° range, the current fast velocity AST data elicits a response whereby the fatigue-induced decrement in strength would be further increased at more extended knee flexion angles. These data therefore have implications for post exercise recovery monitoring and the prescription of recovery modalities. It could however be suggested that the observed response in the AST data is similar to that identified with the PT data and, as such, is there an added benefit of analysing the AST data when considering the additional work associated with the identification of these data? In support of the use of AST, the observed significant decrements in torque were almost double that which was identified from the PT data. This has large implications for monitoring practice, with the potential under estimation of the post exercise fatigue response if only considering PT. In addition to the aforementioned PT data, the analysis of AST also provides an increased appreciation of the torque angle relationship, thus providing the potential to better inform decision making and practice. For example, in support of the APT data, the fast velocity AST data appears to suggest that torque is maintained in knee flexion angles of $\geq$ 55° both immediately following the completion of the SSEP, and over the subsequent 48-hour period. When considering the reported mechanisms of injury associated with KF and knee ligamentous injuries, these data suggest that increased attention should be attributed to the maintenance and subsequent recovery of fast velocity KF torque at extended knee flexion angles. In support of these observations and the potential link to increased injury risk, it has previously been identified that the knee flexors are less completely activated during maximal eccentric actions at long muscle lengths than muscles of uninjured athletes (Sole et al., 2011), thus protecting the injured muscles from high mechanical loads whilst in a compromised position. It has been suggested that this observed response may be due to neural inhibition, thus limiting the recovery of the muscle to shift the APT back towards a more optimal/ pre-fatigued position (Sole et al., 2011).

In relation to the slow velocity AST data, in support of the pre-trial fast velocity AST data, and the aforementioned APT data, torque increased linearly with the highest torque values observed at more extended knee flexion angles. As with the fast velocity AST data, the observed residual reduction in torque was of a greater magnitude when considering the AST data when compared to the PT data. The observed significant interactions observed for the slow velocity data and the somewhat uniform response observed at each measurement point (see figure 3) suggests that the players elicit a shift in the overall magnitude in strength, but the fatigue response post-trial is more exaggerated at extended knee flexion angles. The AST data therefore identifies velocity dependent differences, thus identifying the need to record data across a range of velocities to better inform monitoring and recovery practices.

To standardise post-trial practices of the participants, thus improving methodological rigour, the researchers asked for all participants to abstain from exercise and the use of recovery modalities in the 48-hour period following the completion of the SSEP. The authors appreciate that this would not be common practice in the applied setting; however, they decided that for the focus of the paper, it was best to maintain methodological rigour. A similar approach was also taken with regards to the use of a treadmill-based protocol to ensure that all participants completed the same activity protocol. Although a free-running protocol or the use of match-play would increase the ecological validity of the study and potentially increase the observed fatigue response due to an increased completion of changes in direction and utility movements, the use of these modes would also allow for different pacing strategies to be adopted and differences in activity profiles to occur. It should also be acknowledged that although the current IKD data was recorded in a seated position to aid comparisons across other studies in the literature, the hip positioning could have been altered to better replicate the lower limb joint positions that are more commonly adopted in soccer. The current data is therefore specific to both the testing position used, the musculature assessed, and the nature of the current protocol.

Conclusion

The current data do not only provide descriptive baseline data for the current population and for the novel metrics used, but it also provides an understanding of useful isokinetic metrics when monitoring the recovery of fatigue in the days following exercise. Soccer-specific treadmill running was shown to impair eccentric hamstring strength, supporting epidemiological observations of increased risk of hamstring strain during the latter stages of a match. However, the specific interpretations of the changes in eccentric hamstring strength were sensitive to test speed and choice of peak or angle-specific torque assessments. The potential impact on clinical interpretation and subsequent prescription of training advocates the use of a range of testing velocities, and analysis of strength beyond the peak of the strength-angle curve. The exacerbated risk associated with fixture congestion was investigated by a follow-up assessment 48 hours post-trial. This highlighted continual adaptation in the function of the hamstring musculature, with further deficits in peak strength and an increased angular range over which strength was compromised. The failure to recover strength and the increased range of strength inhibition supports the risk associated with periods of fixture congestion. The residual fatigue response observed in the current metrics (in particular the AST data) has implications for recovery monitoring and the prescription of both recovery strategies and conditioning practices. Knowledge of the recovery response associated with the current isokinetic strength metrics could also be used for future research interested in assessing the influence of different recovery modalities.

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