

Manuscript Title: The cumulative and residual fatigue response associated with soccer-specific activity performed on different playing surfaces.

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Running head:

The cumulative and residual fatigue response to different soccer playing surfaces

Key words: football, artificial, natural, peak torque, isokinetics, Jump height

Abstract

This study aimed to assess the effect of playing surface (Natural [NT] and Artificial [AT] Turf) on the fatigue response to a soccer-specific exercise protocol (SSEP). Eighteen male soccer players completed the SSEP on NT and AT with pre-, post-, and 48h post-assessments of eccentric knee flexor (eccKF) and concentric knee extensor peak torque (PT), peak countermovement (CMJ) and squat jump (SJ) height, and Nordic hamstring break angle. No significant main effects for surface or any surface and time interactions were observed for any of the outcome measures, except for eccKF PT recorded at $180 \text{ deg}\cdot\text{s}^{-1}$, which was significantly lower 48h post-trial in the AT condition (AT= $146.3 \pm 20.4 \text{ Nm}$; NT= $158.8 \pm 24.7 \text{ Nm}$). Main effects for time were observed between pre- and post-trial measures for eccKF PT at all angular velocities, Nordic break angle, CMJ and SJ height. Nordic break angle, and both CMJ and SJ height were significantly impaired 48h post-trial when compared to pre-trial. The findings of the current study suggest surface dependent changes in eccKF PT which may have implications for recovery and subsequent performance after competition on AT.

Introduction

Soccer is traditionally played on natural turf (NT) pitches (Hughes et al., 2013); however, due to the natural variability of NT in addition to advancements in artificial turf (AT), the International Football Association Board (IFAB) introduced artificial turf pitches into the Laws of the Game in 2004 (Nedelec et al., 2013). These surfaces are now regularly used within professional match-play and training facilities (Nedelec et al., 2013) and widely adopted at sub-elite levels (Hughes et al., 2013). Research suggest that no differences exist between surface type and performance metrics including total distance covered and high-intensity exercise during match-play (Anderson, Ekholm and Krstrup, 2008), or the associated physiological response (Hughes et al., 2013; Stone et al., 2016). However, professional soccer players report greater effort during matches played on AT than NT (Andersson, Ekholm and Krstrup, 2008). The increased perceived effort reported on AT may be related to previous findings that have identified that the sprint and agility performance is increased on AT compared to NT, thus potentially resulting in an additional mechanical fatigue response (i.e. changes in movement efficiency and reductions in the force generating capacity) on the AT, especially when players are repeatedly required to perform these activities (Hughes et al., 2013).

Prolonged soccer-specific activity has been reported to elicit cumulative fatigue induced changes in performance, with reductions in high intensity running and sprinting (Mohr et al., 2005), reduced eccentric muscle strength (Page et al., 2019), and an increased risk of injury observed during the latter stages of match-play (Greig and Seigler, 2009; Small, McNaughton, Greig and Lovell, 2010). Furthermore, it has also been suggested that soccer players are susceptible to residual fatigue (i.e. in the days following soccer-specific activity), with changes in biological markers, and reduced eccentric hamstring strength observed in the days following soccer-specific activity (Ispirlidis et al., 2008; Rampinini et al., 2011; Page et al., 2019). This

has led to further research investigating physiological and performance recovery responses to soccer specific activity on different pitch surface types using soccer-specific exercise protocols (SSEPs) (Hughes et al., 2013; Nedelec et al., 2013) to increase experimental control (Stølen et al., 2005; Rollo et al., 2014). However, the SSEPs used often lack ecological validity, typically in relation to the design and structure of the activity profile (Stone et al., 2016), likewise, the outcome measures often neglect the mechanical response to SSEP which is likely to better inform an understanding of aetiological risk factors associated with injury.

Equivocal information exists in relation to injury literature comparing the influence of different playing surfaces during intermittent team sports. For example, previous literature has identified increased ankle injury risk on AT when compared to NT (Calloway et al., 2019), increased overall injury rates on AT when compared to NT (Mack et al., 2019), increased incidence on NT when compared to AT (Meyers 2017), or no differences in overall injury rates across playing surfaces (Steffen, Andersen, and Bahr 2007). Due to differences in methods used between studies, and the potential of contextual factors which may influence between surface comparisons, it is often difficult to develop a cause and effect relationship between surface usage and types of injury. The aetiological mechanisms associated with common injuries are however well known, thus allowing for these mechanisms to be assessed between surfaces and, in turn, allowing for changes in mechanical capacity and performance to be compared between surfaces.

Epidemiological research into high-intensity intermittent team sports including soccer has consistently identified knee ligamentous and thigh muscular strain injuries to be most prevalent (Woods et al. 2004; Renstrom et al. 2008; Ekstrand, Hagglund and Walden, 2011), with reduced muscle strength consistently identified as an aetiological risk factor in the development of these injuries (Nielsen and Yde, 1989; Croisier et al. 2008; Van Dyk et al. 2016). Nedelec

and colleagues (2013) observed cumulative and residual reductions in eccentric hamstring peak torque (PT) on NT when compared to AT. However, the isokinetic dynamometer (IKD) based assessments performed by Nedelec et al., (2013) were conducted at a single isokinetic velocity of 120°s^{-1} , with this relatively slow angular velocity lacking functional relevance when considering reported lower limb aetiology (Eustace et al., 2017). Contemporary research (Eustace et al., 2017) has therefore suggested that isokinetic metrics should be quantified across a range of angular velocities, thus increasing our understanding of the torque velocity relationship and to also better replicate the proposed injury aetiology.

Although IKD analyses provide researchers with increased specificity of torque production, greater cost and expertise is required when compared to commonly utilised field-based measures of lower limb muscular performance. Field based methods may not provide the same level of detailed analysis; however, they are quick and easy to administer, thus aiding potential practical application. Where previous studies that have attempted to compare mechanical fatigue responses across different surfaces, they have often done so using jump performance assessments (Nedelec et al., 2013; Stone et al., 2016); however, these methods have not demonstrated differences in responses between surfaces but are sensitive to cumulative fatigue responses (Stone et al., 2016). The Nordic break angle is a less well researched field-based assessment that is also specific to thigh injury aetiology. This method comprises a 2-dimensional kinematic analysis of a Nordic curl and has been shown to correlate with IKD PT (Sconce et al., 2015). This method has not however been considered in relation to the assessment of cumulative and residual fatigue responses to soccer-specific exercise, nor has it been considered to compare differences in these response between surfaces. Nevertheless, the Nordic break angle assessment offers a novel and easily administered method to infer lower limb muscular strength, without the necessity for complex and/or expensive laboratory-based

methods. Consequently, the aim of the study was to assess the effect of playing surface (NT and AT) on the cumulative and residual fatigue response to a SSEP using both clinical and field-based assessment methods.

Method

Experimental design

This experimental study comprised a randomised crossover design to identify the cumulative (post-trial) and residual (48h post-trial) mechanical fatigue response to prolonged soccer specific exercise performed on both NT and AT. The experimental trials comprised the completion of a contemporary and valid field-based SSEP (Small et al., 2010). The SSEP was used to ensure mechanistic rigor by standardizing both the locomotion and speed profile performed by the participants, so that observed differences in the dependant variables were attributable to fatigue-induced differences. The primary outcome measures of the study were eccentric knee flexor (eccKF) and concentric knee extensor (conKE) torque in the form of isokinetic PT at a range of angular velocities, Nordic break angle and countermovement (CMJ) and squat jump (SJ) height. Outcome measures were recorded pre-exercise, immediately post and 48h after exercise completion.

Participants

Eighteen male soccer players (Age: 24 ± 4 years; Height: 181.1 ± 6.3 cm; Mass: 74.3 ± 6.1 kg) participated in the current study. Inclusion criteria for the study required participants to be outfield soccer players who were injury free, aged 18+ years, had no injuries to the lower limbs in the six months prior to testing, habitually train and play on natural grass, and in addition to weekly matches, possess typical training volumes of >6 h·week⁻¹. All participants provided

written and informed consent prior to the start of the first experimental trial, with ethical approval provided by the host institution ethics committee, conforming to the Declaration of Helsinki.

Procedures

Participants were required to attend the university on five occasions to complete a familiarisation trial, two experimental trials, and two follow up assessments. Follow up assessments were completed 48h after the completion of each experimental trial, to assess the time-course of recovery associated with a number of metrics. Each soccer-specific exercise trial was interspersed with 96h of recovery, with the experimental trials being conducted in a randomised order to prevent a learning effect. Due to the participants being accustomed to playing and training on NT, the familiarisation trial comprised of 2 x 15-minute sections of the SSEP (Lovell et al., 2008) conducted on the AT surface. The familiarisation trial also comprised practice trials (10 repetitions of each assessment type and angular velocity where appropriate) of the IKD, Nordic curls, and both CMJ and SJ assessments. The intraclass correlation coefficients (ICC) data reported within the results section suggests that the familiarisation trial was sufficient to habituate the participants for all measures. All trials were conducted at the same time of day in accordance with the participant's regular training times to control for circadian variation (Rae, Stephenson and Roe, 2015). For each trial, participants were required to consume a minimum of 500 ml of water 2h prior to testing, refrain from caffeine 24h prior to the experimental trials, and attend each session in 3h post-absorptive state, following a 48h period of abstinence from vigorous exercise, the use of recovery strategies, and alcohol consumption. All experimental trials were conducted on days where there was no scheduled rain, no surface water, and no high winds. The AT pitch was "FIFA 1 Star" rated and "World rugby regulation 22 performance specification" compliant third generation

artificial surface (Desso iDNA 60 EL25, Desso Sports) comprising 50mm polypropylene fibres stabilised with rubber granules. The NT was maintained by a professional groundsman and comprised a natural grass surface. One month prior to testing commencing, performance tests were completed on the AT surface by an external accredited test institute (Sports Labs, UK), with compliance with the world rugby regulation 22 performance specification being confirmed and validated for a two-year period. The performance tests comprised the assessment of minimum, maximum, and variance across the pitch surface for measures of shock absorption, vertical deformation, energy restitution, vertical ball rebound, rotational resistance, and impact attenuation, with all measures being within the permitted ranges.

Prior to the completion of each experimental trial, participants were required to complete a 10-minute soccer-specific warm up comprising intermittent running and dynamic stretching. Participants were instructed to wear the same light weight running apparel for each testing session. To remove footwear effects, the same moulded studded football boots were worn throughout the completion of each SSEP.

Soccer-specific exercise protocol

The SSEP utilised within the current study was the free running Soccer Aerobic Field Test (SAFT⁹⁰) developed and validated by Lovell et al., (2008). The protocol incorporates standardised accelerations, decelerations and utility movements over a 20m course, with four poles positioned which the participants are required to navigate, performing either forwards, backwards or sideways running around the first pole, followed by cutting through the middle three poles. Participants completed the protocol in accordance with standardised and timed auditory instructions provided from a CD. This in turn ensured that the running velocities, activities, and distances were standardised between trials. In accordance with time-motion

analysis data (Lovell et al., 2008), over the course of a 90-minute simulation, the SAFT⁹⁰ comprises 1269 changes in speed, 1250 changes in direction (Small et al., 2009), a total distance covered of 10.78km, and an average running velocity of 7.2km·h⁻¹. Due to the standardised nature of the protocol the external workload was matched between trials, thus allowing for any observed differences in the response to the protocol to be attributable to between surface differences.

Experimental measurements

Isokinetic dynamometry

Unilateral eccKF and conKE strength was assessed using the participant's dominant limb, defined as their preferred kicking leg, using an IKD (Biodex Medical System 2, Shirley, New York) at isokinetic speeds of 180, 240 and 60 deg·s⁻¹. The order of the speeds was chosen to reduce the potential fatigue effect induced by the slower isokinetic velocity (Greig., 2008). The range of motion was set at 95–25° of knee flexion. Participants were instructed to complete 3 maximal contractions at each speed and contraction type. Passive knee flexion performed at 60 deg·s⁻¹ separated each repetition (Eustace et al., 2017), with a rest period of 60 seconds interspersing each set (Croisier et al., 2008). To standardise practices between trials and measurement points no performance feedback was provided (Campenella et al., 2000). Each participant was secured in a seated position with approximately 90° 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. 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. 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 PT. Measures of PT were recorded at rest, following the completion of the experimental trials, and 48h post-experimental trial

Functional performance tasks

CMJ and SJ height was recorded using a mobile contact mat (Smartjump, Fusion Sport, Australia). Participants were instructed to wear the same sports shoes (running shoes) for each testing session to reduce the influence of shoe properties on jumping performance (Stefanyshyn & Nigg, 2000; Malisoux, Gette, Urhausen, Bomfim & Theisen, 2017). In an attempt to reduce surface interactions previously reported in the literature (Stone et al., 2016), all functional performance tasks were completed on a standardised concrete surface within the laboratory. For the CMJ, participants were directed to step onto the contact mat and stand in an upright, stationary position with feet shoulder width apart, to flex the knees to 90°, followed by immediately extending at the knees and hips to jump as high as possible, with hands kept on their hips throughout, to reduce the effect of arm swing on performance (Cheng, Wang, Chen, Wu & Chiu, 2008). The same procedure was conducted for the SJ, with the additional instruction of a 3 second pause before jumping added when the knees were flexed to 90°. Two practice trials were allowed prior to each assessment, followed by three recorded trials. A 20 second rest period interspersed each jump (Russel et al., 2018). The peak jumps were utilised for statistical analyses.

Nordic Curl and calculation of break angle

At pre-, post-, and 48h post-trial, each participant was required to perform a total of six Nordic hamstring curls. Three of these trials were completed at a submaximal intensity to allow for the technique to be practiced, and three were used for subsequent analyses. As previously described by Sconce and colleagues (2015), each trial was recorded using a camera (25 Hz) placed in the sagittal plane positioned 5 m away. Kinovea software version 0.8.7 (Kinovea.org) was subsequently used to determine the angle from the greater trochanter (hip) to lateral epicondyle (knee) relative to the horizontal from the recorded video. Nordic curls were performed using methods previously described by Sconce and Colleagues (2015), with the break angle calculated as the angle at which the participant can no longer resist the increasing gravitational moment, subtracted from 180° (horizontal position).

Statistical analyses

The statistical procedures and the associated metrics were decided on *a priori*. The assumptions associated with the general linear model (GLM) were assessed to ensure model adequacy. To assess residual normality for each dependant variable, q-q plots were generated using stacked standardised residuals. Outliers were identified as any standardised residuals that were >3 standard deviations, with eccKF data recorded at 180 deg·s⁻¹ having one participants data removed. Scatterplots of the stacked unstandardized and standardised residuals were also utilised to assess the error of variance associated with the residuals. Mauchly's test of sphericity was also completed for all dependent variables, with a Greenhouse Geisser correction applied if the test was significant. Following the assessment of model adequacy, a 2x3 repeated measures ANOVA was utilized to analyse differences in the cumulative and residual fatigue response recorded between the two experimental trials and associated measures. Where

significant main effects or interactions were observed, post-hoc pairwise comparisons with a least significant difference correction factor were applied. 95% confidence intervals (CI) and 95 % CI for differences (*CI_{diff}*) were also reported. Cohen's *d* effect sizes were calculated using pooled SD data and were classified as trivial (0.20 – 0.49), moderate (0.50–0.79) and large (> 0.80) (Cohen, 1992). For all variables associated with the current study, absolute agreement ICC were calculated from the baseline measures of each trial. These ICC values were interpreted as <0.2 = slight, 0.21–0.4 = fair, 0.41–0.6 = moderate, 0.61–0.8 = substantial, and >0.8 = almost perfect reliability (Landis et al. 1997). The ICC values were also utilised to calculate standard error of measurement (SEM) using the formula: SD Pooled x ($\sqrt{1-ICC}$) (Thomas, Nelson, & Silverman, 2005). All statistical analyses were conducted using PASW Statistics Editor 25.0 for Mac (SPSS, Inc, Chicago, IL, USA), with statistical significance set at $p \leq 0.05$.

Results

Eccentric Knee Flexor Peak Torque

As identified in table 1, no significant trial and time interaction ($F(2,34) = 0.095$; $p = 0.910$), or main effect for trial ($F(1,17) = 0.776$; $p = 0.391$) was observed for the eccKF PT recorded at $60 \text{ deg}\cdot\text{s}^{-1}$. There was however a significant main effect for time ($F(2,34) = 4.567$; $p = 0.034$), with post hoc pairwise comparisons identifying significantly lower values recorded post-trial ($143.6 \pm 26.8 \text{ Nm}$; CI= 131.4 to 155.8 Nm; *CI_{diff}*= -28.0 to -2.2 Nm; $d = 0.6$; $p = 0.024$) when compared to pre-trial ($158.7 \pm 23.5 \text{ Nm}$; CI= 147.6 to 169.7 Nm). Although not significantly different, the data recorded 48h post-trial identified a small recovery towards baseline ($145.0 \pm 28.0 \text{ Nm}$; CI=131.6 to 158.4 Nm; $d = 0.5$); with, the differences recorded between the pre-

trial measures with both the post-trial and 48h post-trial measures being greater than the observed SEM as highlighted in table 1.

As illustrated in table 1, a significant trial and time interaction was identified for the eccKF PT data recorded at 180 deg·s⁻¹ ($F(2,32)= 3.523$; $p = 0.041$). A significant main effect for time ($F(2,32)= 6.682$; $p = 0.009$) was also observed, though no significant main effect for trial ($F(1,16)= 2.306$; $p = 0.148$). Post hoc pairwise comparisons identified significantly lower values recorded post-trial (146.4 ± 19.8 Nm; CI= 138.2 to 154.5 Nm; $CI_{diff}= -21.5$ to -8.6 Nm; $d = 0.8$; $p < 0.001$) when compared to pre-trial (161.4 ± 17.3 Nm; CI= 153.4 to 169.5 Nm). The data recorded 48h post-trial identified a recovery response towards baseline (152.5 ± 23.2 Nm; CI= 142.4 to 162.6 Nm; $d = 0.5$); with, the differences recorded between the pre-trial measures with both the post-trial and 48h post-trial measures being greater than the observed SEM.

There was also no significant trial and time interaction ($F(2,34)= 0.615$; $p = 0.499$), and no significant main effect for trial ($F(1,17)= 0.625$; $p = 0.440$) observed for the eccKF PT data recorded at 240 deg·s⁻¹ (table 1). There was however a significant main effect for time ($F(2,34)= 6.737$; $p = 0.010$), with post hoc pairwise comparisons identifying significantly lower values recorded post-trial (148.8 ± 25.9 Nm; CI= 137.6 to 160.0 Nm; $CI_{diff}= -27.0$ to -7.4 Nm; $d = 0.7$; $p = 0.002$) when compared to pre-trial (166.1 ± 26.4 Nm; CI= 154.3 to 177.8 Nm). A recovery response towards pre-trial measures was identified 48h post-trial (155.1 ± 26.2 Nm; CI= 142.9 to 167.2 Nm; $d = 0.4$); with, the differences recorded between the pre-trial measures with both the post-trial and 48h post-trial measures being greater than the observed SEM.

Concentric Knee Extensor Peak Torque

For all conKE PT data (table 1), the GLM identified no significant trial and time interaction (60 deg·s⁻¹: F(2,34)= 0.307; p = 0.738, 180 deg·s⁻¹: F(2,34)= 0.181; p = 0.835; 240 deg·s⁻¹: F(2,34)= 0.668; p = 0.519), and no significant main effect for trial (60 deg·s⁻¹: F(1,17)= 0.204; p = 0.657, 180 deg·s⁻¹: F(1,17)= 0.547; p = 0.470, 240 deg·s⁻¹: F(1,17)= 0.997; p=0.418) or time (60 deg·s⁻¹: F(2,34)= 3.139; p = 0.080, 180 deg·s⁻¹: F(2,34)= 0.809; p = 0.418, 240 deg·s⁻¹: F(1,17)= 1.148; p = 0.315).

Nordic Break angle

As identified in table 1, no significant trial and time interaction (F= 0.061; p = 0.941), and no significant main effect for trial was observed (F= 0.00; p=1.00). There was however a significant main effect for time (F= 5.737; p = 0.017), with post hoc pairwise comparisons identifying the break angle to be significantly inhibited post-trial (50 ± 5°; CI= 48 to 50°) when compared to both pre-trial (47 ± 4°; CI= 45 to 49°; CI_{diff}= 0 to 7°; d = 0.7; p = 0.037) and 48h post-trial (48 ± 4°; CI= 45 to 50°; CI_{diff}= 1 to 4°; d = 0.4; p = 0.002). The differences recorded from the pre-trial measures to both post-trial and 48h post-trial were greater than the observed SEM.

** Insert table 1 about here **

Countermovement Jump Height

No significant trial and time interaction (F(2,34)= 0.034; p = 0.967), and no significant main effect for trial (F(1,17)= 0.053; p = 0.821) was observed for the CMJ peak jump height data (table 2). There was however a significant main effect for time (F(2,34)= 11.396; p < 0.001),

with post hoc pairwise comparisons identifying significantly higher values recorded pre-trial (36.9 ± 6.8 cm; CI= 33.6 to 40.3 cm) when compared to post-trial (35.6 ± 6.8 cm; CI= 32.2 to 39.0 cm; CI_{diff} = 1.0 to 4.1 cm; $d = 0.2$; $p = 0.009$) and 48h post-trial (34.4 ± 6.3 cm; CI= 31.3 to 37.6 cm; CI_{diff} = 0.7 to 3.5 cm; $d = 0.4$; $p = 0.001$). The differences recorded between the pre-trial measures with both the post-trial and 48h post-trial measures were greater than the observed SEM.

Squat Jump Height

No significant trial and time interaction ($F(2,34) = 0.562$; $p = 0.575$), and no significant main effect for trial ($F(1,17) = 0.50$; $p = 0.826$) was observed for the SJ peak jump height data (table 2). There was however a significant main effect for time ($F(2,34) = 8.027$; $p = 0.001$), with post hoc pairwise comparisons identifying significantly higher values recorded pre-trial (36.9 ± 7.3 cm; CI= 33.3 to 40.5 cm) when compared to both post-trial (35.0 ± 7.2 ; CI= 31.5 to 38.5 cm; CI_{diff} = 0.4 to 3.3 cm; $d = 0.3$; $p = 0.10$) and 48h post-trial (34.3 ± 6.0 cm; CI= 31.3 to 37.3 cm; CI_{diff} = 0.6 to 4.6 cm; $d = 0.4$; $p = 0.10$). The differences recorded from the pre-trial measures with both the post-trial and 48h post-trial measures were greater than the observed SEM.

** Insert table 2 about here **

Discussion

The aim of the study was to assess the effect of playing surface (NT and AT) on the cumulative and residual fatigue response to a SSEP. With the exception of eccKF PT recorded at $180 \text{ deg} \cdot \text{s}^{-1}$, there were no main effects for surface, or any surface and time interactions observed for any of the outcome measures. The eccKF PT data recorded at $180 \text{ deg} \cdot \text{s}^{-1}$ was shown to be

significantly lower 48h post-trial in the AT condition (146.3 ± 20.4 Nm) when compared to the NT condition (158.8 ± 24.7 Nm), with this difference being greater than the observed SEM (8.6 Nm). These data therefore suggest an impaired recovery response following the completion of soccer-specific exercise on AT. Irrespective of surface, impaired performance was also observed between pre- and post-trial measures for eccKF PT data recorded at all angular velocities, Nordic break angle, and the CMJ and SJ metrics. It was identified that the CMJ and SJ metrics were also significantly lower 48h post-trial when compared to pre-trial. The Nordic break angle data was also significantly higher post-trial when compared to 48h post-trial. The findings of this study suggest that performance and fatigue profiles are similar between surface types expect for eccKF PT at $180\text{deg}\cdot\text{s}^{-1}$. The change in eccKF PT may have potential recovery and subsequent performance implications; however, this requires further exploration.

The incidence of thigh musculature and knee joint injuries is a primary concern in football (Ekstrand et al. 2011). When considering the typical injury aetiology associated with knee flexor injuries (Woods et al. 2004), the observed reduction in the eccKF PT data recorded (at $180\text{ deg}\cdot\text{s}^{-1}$) following the completion of AT based activity might have implications for injury risk (Mack et al., 2019) and performance (Rahnamma et al., 2003) across subsequent days of training or match-play. The observed reduction in eccKF PT may be attributable to previous observations of increased horizontal peak accelerations during slalom running (a characteristic of the current SSEP) on AT when compared to NT (Zanetti et al., 2013). These data may also help to explain why players report higher perceptions of effort and muscle soreness when competing on AT (Andersson et al., 2008). The current data does however contrast the findings of Nedelec and colleagues (2013) who identified that eccKF PT recorded at $120\text{ deg}\cdot\text{s}^{-1}$ was significantly lower in the days following prolonged intermittent activity on NT when compared

to AT. It should however be acknowledged that the participants in the Nedelec study were accustomed to playing on AT whereas those recruited in the current study were regularly exposed to training and match-play on NT. The contrasting findings of the current data to that of Nedelec et al., (2013) therefore appears to suggest that chronic habituation to a surface may alter the residual fatigue response associated with it. Practitioners should therefore consider the observed differences in the rate of recovery between playing surfaces, and account for this with session design and recovery prescription. Future research may want to consider the influence of this residual fatigue response on subsequent match-play, especially during congested training and match schedules (Page et al., 2019).

The current residual fatigue response observed for the eccKF data was only identified as being statistically different between trials at knee angular velocities of $180 \text{ deg}\cdot\text{s}^{-1}$. Although not directly measured, the increase magnitude of difference identified at moderate angular velocities may be indicative of the average running velocity ($7.2 \text{ km}\cdot\text{h}^{-1}$) and therefore the knee angular velocities associated with the completion of the SSEP. However, although not significantly different, a reduced rate of recovery (i.e. mean difference between the 48h post-trial measure and the resting measure), was also identified in the AT trial for the PT data recorded at $240 \text{ deg}\cdot\text{s}^{-1}$ for both eccKF and conKE assessments, and conKE data at 60 and $180 \text{ deg}\cdot\text{s}^{-1}$. Except for the conKE data recorded at $180 \text{ deg}\cdot\text{s}^{-1}$, these differences were greater than the SEM and, as such, it could be suggested that the specific torque values remained impaired to a meaningful amount following the AT trial. This same response was not observed in the NT trial, where the rate of recovery was within the SEM. The current data does emphasise the importance of considering a range of knee angular velocities and assessments of different musculature (Eustace et al., 2017). The observed lack of cumulative or residual fatigue for the

conKE PT data is in support of previous literature that has suggested that players are able to maintain KE torque during the completion of prolonged intermittent activity (Greig 2008).

The lack of interactions observed for the CMJ and SJ data may also be related to predominant contribution of the KE musculature to jump performance and the observed lack of differences observed between trials for the KE PT data. The current CMJ jump data is however in support of previous literature, with Stone et al., (2016) and Nedelec et al., (2013) identifying no between surface differences. In further support of the current study, Nedelec et al., (2013) identified a cumulative fatigue response in jump performance following the completion of the same SSEP. However, in contrast to the current study, Nedelec et al., (2013) identified larger cumulative and residual decrements in SJ height on AT when compared to NT. The inconsistencies in responses reported between studies raise questions in relation to sensitivity of jump height assessments in detecting differences in the fatigue response associated with different playing surfaces.

The current study is, to the author's knowledge, the first to consider the use of the Nordic break angle metric to quantify a cumulative and residual fatigue response to soccer-specific activity. It was identified that the metric is sensitive to cumulative fatigue; however, the break angle returned towards baseline measures 48h post-trial. The Nordic break angle metric appears to mirror that of the eccKF PT data recorded at $60 \text{ deg}\cdot\text{s}^{-1}$. These data therefore suggest that the Nordic break angle assessment could offer an easily administered method to infer changes in lower limb muscular function. However, as previously discussed, the monitoring of the post exercise recovery response does require a range of assessment methods and metrics that better replicate the functional demands and aetiology of soccer-specific exercise and injury risk.

Limitations

Although the need to standardise the activity profile between trials was fundamental to the current study, the use of a SSEP negates the inclusion of some soccer-specific utility movements such as, but not limited to, jumping, kicking, tackling which can further induce muscle damage and influence the rate of recovery post-exercise (Small et al., 2009). As such, the current data may be considered to provide a conservative mechanical response when compared to soccer match-play, thus further reiterating the implications of the current data. Recent research has advocated the improved quantification and description of surfaces characteristics; however, this was not possible in the current study due to limited access to specialist equipment. The observed response may therefore be specific to the current population and the surface characteristics associated with the current study. As previously discussed, the participant's habituation towards the NT may also have influenced the observed response and, as such, future research may therefore want to consider the inclusion of participants who are habituated to different surfaces.

Conclusion

With the exception of eccKF PT recorded at $180 \text{ deg}\cdot\text{s}^{-1}$, there were no main effects for surface or any surface and time interactions observed for any of the outcome measures, thus suggesting limited between surface differences. Soccer-specific exercise performed on AT was shown to residually impair eccKF PT recorded at $180 \text{ deg}\cdot\text{s}^{-1}$ when compared to the same exercise performed on NT. These data therefore support previous observations of increased perceptions of effort whilst performing on AT and the previously observed increased mechanical demands associated with the completion of utility movements on these surfaces. Practitioners should therefore consider the observed differences in the residual fatigue response elicited by the

different playing surfaces, and account for this with session design and recovery prescription. These data may also help to explain previous observations of increased injury risk observed on AT surfaces; however, additional research is required to try and assess the mechanisms associated with this observed injury risk. The current observations were however in contrast with other findings (Nedelec et al., 2013); who identified increased residual hamstring PT decrement following exercise on NT when compared to AT. These differences in observations do however appear to be a result of the surface upon which the participant is accustomed to, thus further emphasising the potential increased fatigue associated with a non-accustomed surface, and the need to monitor and adjust for this with recovery and training design. The observed reduction in eccKF PT at only one specific angular velocity also further emphasises the need to conduct IKD analyses across a range of angular velocities.

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Table1. Overview of the isokinetic peak torque and Nordic break angle data recorded across trials and measurement points. * denotes a significant difference with the corresponding time point in the AT trial.

		NT			AT			ICC	SEM
		pre-trial	post-trial	48hr post-trial	pre-trial	post-trial	48hr post-trial		
eccKF PT (Nm)	60 deg·s ⁻¹	160.5 ± 23.5 (CI= 148.9 to 172.3)	144.7 ± 28.5 (CI= 130.6 to 158.9)	145.4 ± 28.6 (CI= 131.2 to 159.6)	156.8 ± 24.0 (CI= 144.9 to 168.8)	142.5 ± 25.8 (CI= 129.6 to 155.3)	144.6 ± 28.3 (CI= 130.5 to 158.65)	0.856	8.9
	180 deg·s ⁻¹	160.6 ± 19.3 (CI= 150.6 to 170.5)	147.7 ± 19.6 (CI= 137.6 to 157.8)	158.8 ± 24.7* (CI= 146.1 to 271.4; Mdiff= 12.5; CI _{diff} =0.8 to 24.1; d= 0.6; p = 0.038)	162.3 ± 15.5 (CI= 154.3 to 170.3)	145.0 ± 14.4 (CI= 137.6 to 152.4)	146.3 ± 20.4 (CI= 135.8 to 156.8)	0.753	8.6
	240 deg·s ⁻¹	167.2 ± 27.4 (CI= 153.5 to 180.8)	149.2 ± 26.0 (CI= 136.3 to 162.2)	158.6 ± 28.0 (CI= 144.7 to 172.5)	164.9 ± 22.2 (CI= 153.9 to 176.0)	148.4 ± 25.7 (CI= 135.6 to 161.2)	151.5 ± 27.6 (CI= 137.8 to 165.3)	0.866	10.1
conKE PT (Nm)	60 deg·s ⁻¹	213.0 ± 32.9 (CI=196.6 to 229.3)	201.1 ± 38.4 (CI=182.0 to 220.2)	205.3 ± 34.0 (CI=188.4 to 222.2)	214.5 ± 35.3 (CI= 196.9 to 232.1)	198.9 ± 39.8 (CI= 179.1 to 218.7)	201.1 ± 37.8 (CI= 182.3 to 219.8)	0.844	11.7
	180 deg·s ⁻¹	175.7 ± 23.1 (CI= 164.3 to 187.2)	171.4 ± 28.0 (CI= 157.5 to 185.4)	171.9 ± 27.5 (CI= 158.2 to 185.6)	179.0 ± 24.5 (CI= 166.8 to 191.2)	174.3 ± 29.9 (CI= 159.5 to 189.2)	172.4 ± 28.8 (CI= 158.1 to 186.7)	0.799	10.5
	240 deg·s ⁻¹	162.2 ± 19.9 (CI= 152.3 to 172.0)	158.9 ± 21.5 (CI= 148.2 to 169.6)	159.0 ± 23.0 (CI= 147.6 to 170.5)	166.4 ± 27.1 (CI= 152.9 to 179.8)	161.8 ± 27.0 (CI= 148.3 to 175.2)	158.6 ± 26.3 (CI= 145.5 to 171.6)	0.726	7.6
Nordic Break Angle (°)		47 ± 4 (CI= 45 to 49)	50 ± 5 (CI= 48 to 53)	48 ± 5 (CI= 45 to 50)	47 ± 4 (CI= 45 to 49)	51 ± 6 (CI= 48 to 53)	48 ± 6 (CI= 45 to 51)	0.935	1

Abbreviations: AT= Artificial Turf; conKE= Concentric Knee Extensor; CI_{diff}= Confidence Intervals for Differences; CI= Confidence Intervals; eccKF= Eccentric Knee Flexor; ICC= Intraclass Correlation Coefficient; Nm= Newton Metre; NT= Natural Turf; Mdiff= Mean Difference; SEM= Standard Error of Measurement.

Table 2. Overview of the peak countermovement and squat jump data recorded across trials and measurement points. Data presented as mean \pm SD unless otherwise stated.

	NT			AT			ICC	SEM
	pre-trial	post-trial	48hr post-trial	pre-trial	post-trial	48hr post-trial		
CMJ (cm)	36.9 \pm 6.7 (CI= 33. 6 to 40.3)	35.6 \pm 7.2 (CI= 32.0 to 39.2)	34.5 \pm 6.4 (CI= 31.2 to 37.5)	37.0 \pm 7.0 (CI= 33.5 to 40.4)	35.6 \pm 6.5 (CI= 32.4 to 38.9)	34.5 \pm 6.4 (CI= 31.3 to 37.7)	0.987	0.8
SJ (cm)	37.0 \pm 6.8 (CI= 33.6 to 40.4)	35.3 \pm 8.2 (CI= 31.2 to 39.4)	34.1 \pm 6.0 (CI= 31.1 to 37.1)	36.8 \pm 8.0 (CI= 32.8 to 40.8)	34.7 \pm 6.4 (CI= 31.5 to 37.9)	34.5 \pm 6.2 (CI= 31.4 to 37.6)	0.965	1.4

Abbreviations: AT= Artificial Turf; ; CI= Confidence Intervals; cm= Centimetre; CMJ= Countermovement jump; ICC= Intraclass Correlation Coefficient; NT= Natural Turf; SEM= Standard Error of Measurement; SJ=Squat Jump;