

Contemporary approaches to isokinetic strength assessments in professional football players

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Contemporary Approaches to Isokinetic Strength Assessments in Professional Football Players

Journal:	<i>Science and Medicine in Football</i>
Manuscript ID	RSMF-2016-0166.R2
Manuscript Type:	Original Papers
Keywords:	Screening, Peak torque, injury risk, Angle of Peak Torque, Dynamic Control Ratio
Abstract:	<p>To assess traditional and novel isokinetic strength characteristics of the knee flexor (eccKF) and extensor (conKE) musculature, 26 professional football players completed bilateral conKE and eccKF contractions at angular velocities of 180, 270, and 60 deg•s⁻¹. Values of peak torque (PT), angle of peak torque (APT), angle-specific torque (AST) analysed every 10° between 40 and 70°, functional range (FR), and dynamic control ratios (DCR) calculated from both the PT (DCRPT) and AST data (DCRAST) were analysed. The PT, APT, and FR data elicited a significant contraction*angular velocity interactions (P< 0.001). Significant main effects for contraction*angular velocity*angle and contraction*angular velocity*limb*angle interactions (P< 0.001) were identified for AST data. The DCRPT data elicited a significant main effect for angular velocity (P< 0.001) and limb (P= 0.018), whereas the DCRAST data was significantly different across angles (P< 0.001) and elicited a significant (P= 0.002) limb*angle interaction. Traditional methods and metrics utilised for isokinetic strength assessments in football may not be appropriate and/or sensitive enough to identify injury risk and, as such, practitioners should utilise the novel metrics proposed in the current study and conduct assessments across a range of joint angles and angular velocities.</p>

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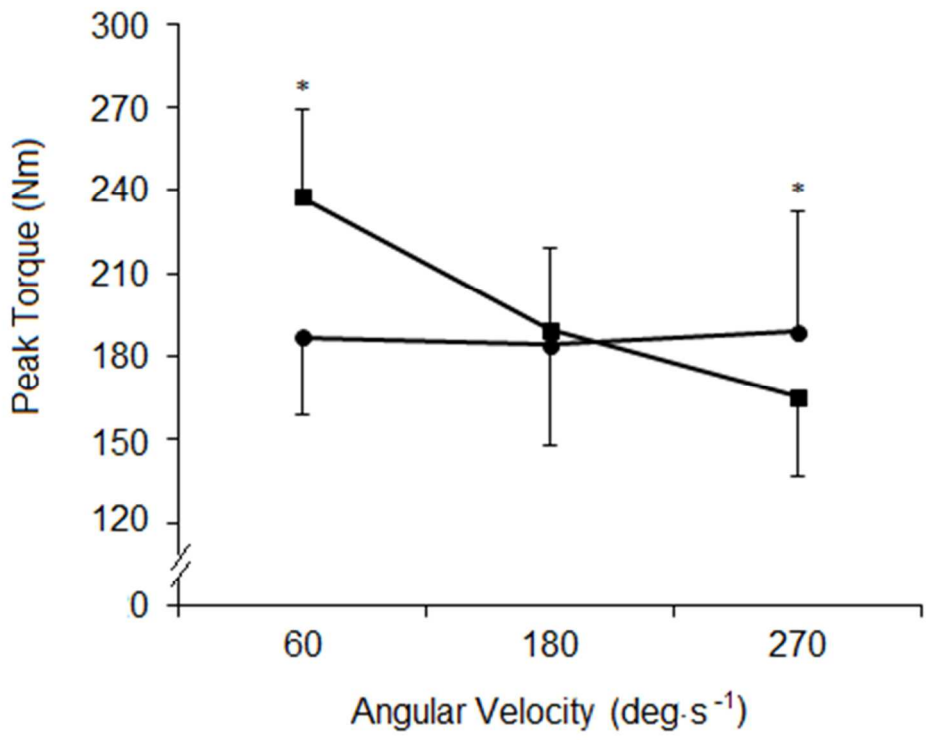


Figure 1. The influence of angular velocity on conKE (■) and eccKF (●) PT. * denotes significant difference between contraction types.

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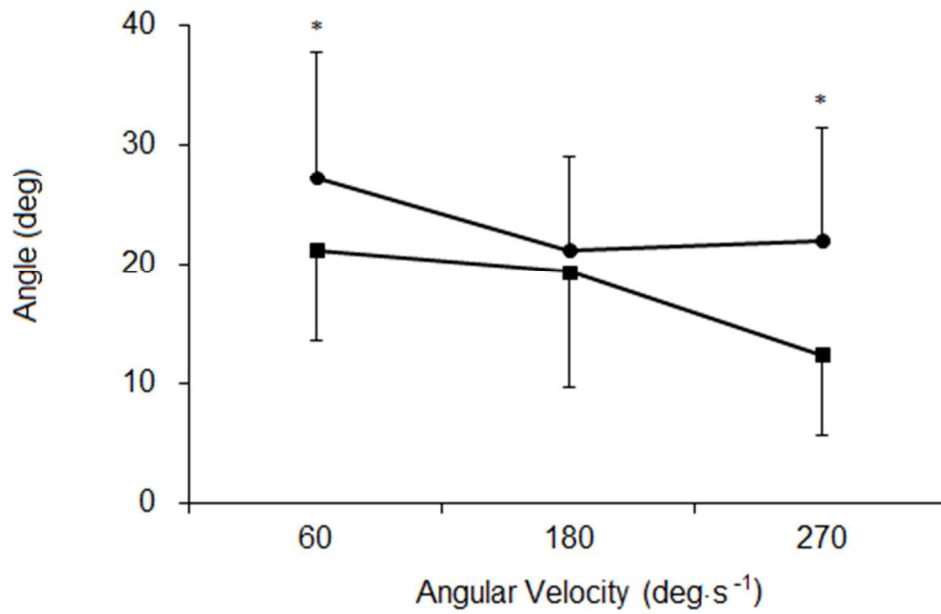


Figure 2. The influence of angular velocity on the FR (at 85% PT) in conKE (■) and eccKF (●). * denotes significant difference between contraction types.

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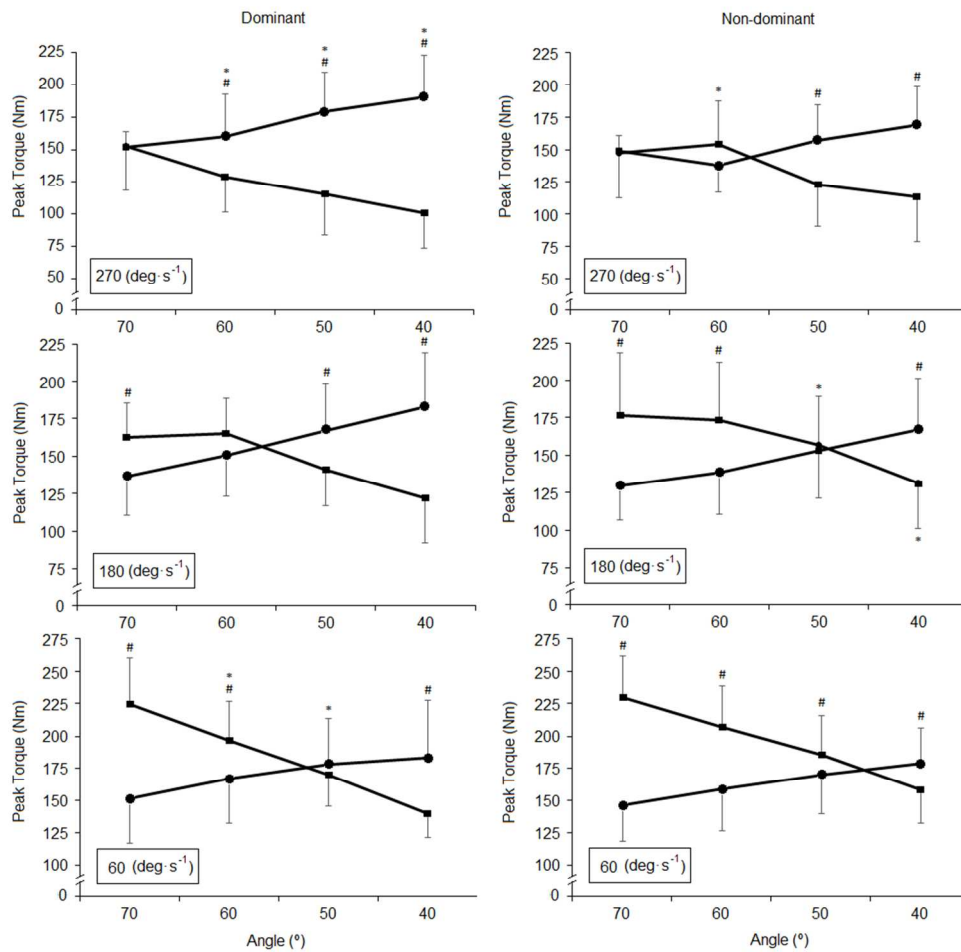


Figure 3. The influence of angular velocity on AST for conKE (■) and eccKF (●) * denotes significant difference between limbs. # denotes significant difference between contraction types.

190x188mm (300 x 300 DPI)



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For Peer Review Only

Abstract

To assess traditional and novel isokinetic strength characteristics of the knee flexor (eccKF) and extensor (conKE) musculature, 26 professional football players completed bilateral conKE and eccKF contractions at angular velocities of 180, 270, and 60 deg·s⁻¹. Values of peak torque (PT), angle of peak torque (APT), angle-specific torque (AST) analysed every 10° between 40 and 70°, functional range (FR), and dynamic control ratios (DCR) calculated from both the PT (DCR_{PT}) and AST data (DCR_{AST}) were analysed. The PT, APT, and FR data elicited a significant contraction*angular velocity interactions ($P < 0.001$). Significant main effects for contraction*angular velocity*angle and contraction*angular velocity*limb*angle interactions ($P \leq 0.001$) were identified for AST data. The DCR_{PT} data elicited a significant main effect for angular velocity ($P < 0.001$) and limb ($P = 0.018$), whereas the DCR_{AST} data was significantly different across angles ($P < 0.001$) and elicited a significant ($P = 0.002$) limb*angle interaction. **Traditional methods and metrics utilised for isokinetic strength assessments in football may not be appropriate and/or sensitive enough to identify injury risk and, as such, practitioners should utilise the novel metrics proposed in the current study and conduct assessments across a range of joint angles and angular velocities.**

Key Terms

Screening, Peak torque, Injury risk, Angle of Peak torque, Dynamic control ratio

1.0 Introduction

Epidemiological research into high-intensity intermittent team sports including soccer (football) 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). These injuries can lead to large financial (Mather et al. 2013) and time loss implications (Walden et al. 2016). Walden et al. reported that only 65% of professional male players that sustained an Anterior Cruciate Ligament (ACL) injury were able return to previous competitive levels. The aetiology of knee ligamentous, knee flexor and extensor muscular injury has consistently identified reduced muscle strength as a risk factor (Nielsen and Yde, 1989; Croisier et al. 2008; Van Dyk et al. 2016).

The assessment of knee extensor and flexor strength is often conducted using isokinetic dynamometry. However, literature to date has identified a limited association between injury incidence and the commonly utilised isokinetic indices of strength (Bennell et al. 1998; Sharira et al. 2016). This lack of association might be attributed to the ways in which isokinetic strength characteristics are typically assessed and quantified. One of the most commonly utilised isokinetic metrics is that of peak torque (PT), which represents a single maximum to describe the torque-angle relationship at a predetermined velocity. This peak value negates an understanding of the sensitivity of strength to changes in angle, or how strength is maintained over the predetermined angular range. The angle of PT has been reported at $\sim 70^\circ$ (from full extension) during concentric knee extensor contractions and $\sim 35^\circ$

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3 for eccentric knee flexor contractions in football players (Small et al. 2010).
4
5 This lack of angular coincidence has led to the development of angle-specific
6
7 derivations of dynamic strength ratios (El-Ashker et al. 2015; Evangelidis et
8
9 al. 2015). The use of angle-specific torque data has been advocated more
10
11 broadly, given the increased risk of musculature and ligamentous injury at
12
13 extended knee joint angles (Boden and Dean, 2000; Olsen et al. 2004;
14
15 Hewett and Myer, 2011; Chumanov et al. 2012; Higashihara et al. 2015).
16
17 However, whilst angle specific measures of isokinetic strength have been
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19 assessed in recreational and semi-professional football populations (Cohen
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21 et al. 2015; El-Ashker et al. 2015; Evangelidis et al. 2015), this profiling has
22
23 not included professional players.
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30 An additional metric often reported in isokinetic analyses defines 'work' as
31
32 the integral of the torque-angle curve, which Dvir (2014) considered of little
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34 relevance given its strong correlation with PT and the influence of
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36 (predetermined and standardised) range of motion. However, the capacity to
37
38 quantify the maintenance of strength throughout an angular range would
39
40 have clinical relevance. The predetermined angular velocity is also a
41
42 methodological issue in isokinetic dynamometry, with assessments often
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44 conducted at low angular velocities of $\leq 120^{\circ}\cdot\text{s}^{-1}$ (Small et al., 2010)
45
46 representing limited functional relevance. The most common mechanism of
47
48 non-contact lower-limb injury in football is running (Ekstrand et al., 2011),
49
50 characterised by knee angular velocities of up to $400^{\circ}\cdot\text{s}^{-1}$ (Nedergaard et al.,
51
52 2014). Whilst the choice of angular velocity is ultimately limited by the
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54 dynamometer used, an inclusion of higher angular velocities is advocated.
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3 When considering aetiological risk factors for lower limb injury in soccer, the
4 current practices associated with isokinetic strength assessments may not be
5 entirely suitable for identifying injury risk. Angle specific strength
6 assessments across a range of angular velocities may offer a better method
7 of identifying strength deficits/imbbalances specific to the injury mechanisms
8 and, in turn, provide additional information pertinent to injury prevention
9 strategies.
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12 With implications for current strength screening practices, the aim of this
13 study was to assess traditional and novel isokinetic eccentric knee flexor
14 (eccKF) and concentric knee extensor (conKE) strength characteristics of
15 professional male football players across a range of joint angles and angular
16 velocities.
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20 21 22 23 24 25 26 27 28 29 30 31 32 33 **2.0 Methods**

34 35 36 **2.1 Participants**

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38 An *a priori* power calculation from pilot study data identified that a sample
39 size of 26 was required to evaluate the interactions for all independent
40 variables (for statistical power .0.8; $P \leq 0.05$). A convenient sample of twenty
41 six professional male football players (age 26.19 ± 4.65 years; height 181.65
42 ± 5.71 cm; mass 82.19 ± 9.01 kg) was therefore recruited for the current
43 study. The participants were all full-time professional football players
44 competing in the English football league two. Inclusion criteria specified that
45 the participants demonstrated the capacity to complete a familiarisation trial
46 specific to the experimental trial, were outfield players and were injury free
47 for a minimum of 6 months prior to testing. In the two weeks prior to testing,
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3 the participants all completed training volumes of $> 10 \text{ h}\cdot\text{week}^{-1}$ in addition to
4
5 weekly friendly matches. The current study was conducted following an 8-
6
7 week pre-season schedule, immediately prior to the commencement of the
8
9 2016-2017 season.
10

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12 For risk stratification, all participants were required to complete a health
13
14 screening procedure prior to commencement of each trial. The health
15
16 screening procedure comprised the completion of a health, physical activity
17
18 and pre-exercise control questionnaire and the measurement of resting heart
19
20 rate and blood pressure. Values of $>90 \text{ beats}\cdot\text{min}^{-1}$ and $>140 \text{ mmHg}/90$
21
22 mmHg respectively were contraindications to exercise. Participants were
23
24 informed of the risks and procedures involved in testing and were required to
25
26 provide written informed consent prior to the commencement of the study.
27
28 The experimental protocol was previously approved by the local university
29
30 ethics committee and conformed to the Declaration of Helsinki.
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37 2.2 Experimental design

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39 Participants were required to attend the laboratory on two occasions to
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41 complete a familiarisation trial followed by a single experimental trial,
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43 separated by a minimum of 96 hours. In an attempt to control for circadian
44
45 variation (Rae, Stephenson, and Roden, 2015), all experimental trials were
46
47 completed in accordance with the participant's regular training times
48
49 (between 10am and 12pm). Participants were instructed to attend the
50
51 laboratory on each occasion in a 3hr post-absorptive state following a 48
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53 hour abstinence of alcohol consumption. In an attempt to reduce the
54
55 influence of residual fatigue on the current data, a 48 hour rest-period from
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3 exercise was also factored into the players weekly microcycle. This was
4 made possible due to the completion of the testing at the end of the pre-
5 season period. Prior to the start of each trial, the isokinetic dynamometer
6 was calibrated in accordance with the manufacturer's guidelines. During the
7 completion of the calibration procedure, the participants were required to
8 complete a standardised 5 minute warm-up on a stationary cycle ergometer
9 (Monark, 824E, Sweden) at 60 W.
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21 The experimental trial comprised the completion of a bilateral profile of the
22 participant's eccKF and conKE isokinetic torque-angle relationship at angular
23 velocities completed in the order of 180, 270, and 60 °·s⁻¹ (Greig, 2008) on
24 an isokinetic dynamometer (IKD) (system 4, Biodex Medical Systems,
25 Shirley, New York, USA) with the dominant leg defined as the preferred
26 kicking leg. For each leg, and at each angular velocity and contraction type,
27 participants were instructed to perform 3 maximal contractions through their
28 full range of movement. Passive knee flexion performed at 60 °·s⁻¹ separated
29 each repetition and a rest period of 60 seconds interspersed each set. No
30 performance feedback was provided during any of the experimental trials.
31
32 The dynamometer setup was adjusted specifically for each participant in line
33 with the manufacturer's guidelines, with the cuff of the lever arm secured
34 around the ankle proximal to the malleoli. Each participant was secured in a
35 seated position with approximately 90° of hip flexion, with restraints applied
36 proximal to the knee joint across the thigh, across the waist, and across the
37 participant's chest. The lever arm was aligned with the axis of rotation of the
38 knee joint and the anatomical reference was set at 90°.
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2.3 Data Analysis

The isokinetic phase (disregarding torque overshoot) of each repetition was analysed and the repetition eliciting the highest angular velocity-corrected torque was subject to further analysis. Peak torque (PT) and the corresponding angle of peak torque (APT) were identified, in addition to a novel measure of functional range (FR). This FR metric was defined as the range over which 85% of PT was maintained, since a 15% decrease in PT has been associated with an increased risk of injury (Croisier et al. 2008). This FR measure also provides a measure of the torque-angle profile, a larger FR indicative of a PT value that is less sensitive to joint angle. Angle specific torque (AST) data was calculated at 10° increments across an angular range (between 40 and 70°) for all angular velocities. Strength ratios were defined as the traditional dynamic control ratio, derived from the peak eccKF and conKE values (DCR_{PT}) and angle-specific dynamic control ratios (DCR_{AST}) calculated from the AST data. In subsequent sections these parameters are annotated according to angular velocity, so that peak torque at 60 °·s⁻¹ is labelled as PT₆₀. For all independent variables associated with the current study, inter-class correlation coefficients (ICC's) were calculated between 0.77 and 0.82.

2.4 Statistical Analysis

The variables that were to be included were decided *a priori*. The aforementioned measures did not violate any of the assumptions, therefore inferential analyses were performed. Inferential analyses were performed using a repeated measure general linear model (GLM) to examine

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3 differences in the isokinetic data. Where significant main effects or
4 interactions were observed, post hoc pairwise comparisons with a
5 Bonferonni correction factor were applied. For all significant main effects and
6 interactions, 95% confidence intervals (CI) for differences are also
7 presented. All statistical analysis was completed using PASW Statistics
8 Editor 22.0 for windows (SPSS Inc, Chicago, USA). Statistical significance
9 was set at $P \leq 0.05$. All data is reported as mean \pm standard deviation (SD)
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20 21 22 23 **3.0 Results**

24 25 **3.1 Peak Torque**

26
27 Figure 1 summarises the relationship between PT and angular velocity for
28 eccKF and conKE. The GLM identified a significant contraction*angular
29 velocity interaction ($P < 0.001$), with significantly higher values recorded for
30 conKE (240.0 ± 31.6 N.m) data recorded at $60^\circ \cdot s^{-1}$ when compared to the
31 eccKF data (188.7 ± 27.2 N.m; CI: 34.5 to 64.7 N.m; $P < 0.001$) and
32 significantly higher eccKF (190.7 ± 43.8 N.m) data recorded at $270^\circ \cdot s^{-1}$ when
33 compared to the conKE data (166.7 ± 28.7 N.m; CI: 9.9 to 33.9 N.m; $P =$
34 0.001). The GLM did not however identify a significant limb*angular velocity
35 ($P = 0.087$) or limb*contraction*angular velocity interactions ($P = 0.192$).
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50 ****Figure 1 near here****
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54 55 **3.2 Functional Range**

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3 The influence of angular velocity and contraction on the FR is summarised in
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5 Figure 2. The GLM identified a significant ($P < 0.001$) contraction*angular
6
7 velocity interaction with significantly higher eccKF FR ($27 \pm 11^\circ$) at $60^\circ \cdot s^{-1}$
8
9 when compared to the conKE FR data recorded at the same angular velocity
10
11 ($21 \pm 8^\circ$; CI: 2 to 10° ; $P = 0.020$). Additionally, eccFK FR ($22 \pm 8^\circ$) at $60^\circ \cdot s^{-1}$
12
13 was significantly higher than conKE FR data recorded at the same angular
14
15 velocity ($21 \pm 8^\circ$; CI: 2 to 10° ; $P = 0.020$). There was however no significant
16
17 limb*contraction ($P = 0.678$), limb*contraction*angular velocity ($P = 0.130$), nor
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19 limb*contraction*angular velocity ($P = 0.382$) interactions.
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26 ****Figure 2 near here****
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29 3.3 Angle of Peak Torque

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31 Table 1 summarises the influence of angular velocity on APT. The GLM
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33 revealed a significant ($P < 0.001$) contraction*angular velocity interaction.
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38 ****Table 1 near here****
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43 3.4 Dynamic Control Ratio Calculated from PT Data

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45 A significant main effect for limb was identified, with significantly higher
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47 values recorded for the dominant limb (1.02 ± 0.06) when compared to the
48
49 non-dominant limb (0.93 ± 0.20 ; CI: 0.01 to 0.17; $P = 0.018$). DCR_{PT}
50
51 increased as a main effect for angular velocity ($P < 0.001$), with DCR_{PT270}
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53 (1.16 ± 0.25) being significantly higher than DCR_{PT180} (0.98 ± 0.25 ; CI: 0.10
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3 to 0.25; $P < 0.001$) and DCR_{PT60} (0.79 ± 0.22 ; CI: 0.26 to 0.46; $P < 0.001$). No
4
5 significant limb*angular velocity interaction was identified ($P = 0.070$).
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10 3.5 Dynamic Control Ratio calculated from the AST data

11 **Table 2** summarises the influence of limb dominance and DCR_{AST} , with a
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13 significant limb*angle interaction being identified ($P = 0.002$).
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22 3.6 Angle Specific Torque

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24 Figure 3 summarises the influence of joint angle on the angle matched
25
26 conKE and eccKF torque at each angular velocity. The GLM identified
27
28 significant contraction*angular velocity*angle ($P < 0.001$) and
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30 contraction*angular velocity*limb*angle ($P = 0.001$) interactions, as identified
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32 in Table 3.
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41 ****Figure 3 near here****
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45 **4.0 Discussion**

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47 The incidence of thigh musculature and knee joint injuries is a primary
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49 concern in football (Ekstrand et al. 2011; Hagglund et al. 2013). The primary
50
51 aim of this study was to conduct a comprehensive isokinetic profile of the
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53 knee flexors and extensors in professional male players. The PT exhibited a
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55 significant contraction*angular velocity interaction; whilst eccKF strength was
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3 maintained, conKE strength decreased as a function of increasing angular
4 velocity. The DCR was subsequently greatest at the highest angular velocity,
5 with greater eccKF strength compared to conKE at angular velocities >
6 $200^{\circ}\cdot\text{s}^{-1}$.
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14 The eccKF also exhibited a significantly greater FR at the highest angular
15 velocity. The FR is used to consider the shape of the strength curve, with a
16 higher value indicative of a capacity to maintain $\geq 85\%$ of PT (Croisier et al.,
17 2008) across a broader range of motion. The FR was higher for the eccKF at
18 all angular velocities, but exhibited a contraction*angular velocity interaction
19 whereby range decreased with increasing angular velocity. **When**
20 **considering the typical injury aetiology associated with knee flexor injuries**
21 **(Woods et al. 2004), the observed reduction in FR at high velocities might**
22 **have implications for injury risk during the completion of ballistic movements.**
23 **Practitioners involved in injury screening should therefore consider a players**
24 **ability to maintain strength over a given range of motion (i.e. FR) at high**
25 **angular velocities.**
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43 The DCR data also exhibited a main effect for limb, with higher values
44 recorded for the dominant limb. There was however no difference between
45 limbs for PT, **thus supporting previous observations of no significant bilateral**
46 **strength differences in elite soccer players** (Fousekis, Tsepis and Vagenas,
47 2010; Daneshjoo et al., 2013). In contrast, the AST data was significantly
48 higher in the dominant knee flexor musculature, with more pronounced
49 differences recorded at increased knee extension angles. Isokinetic profiling
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3 should therefore incorporate the analysis of AST data to identify potential
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5 bilateral asymmetries which may predispose players to greater risk of injury
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7 (Croisier et al. 2008; Kim and Hong, 2011). This is of particular importance
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9 given the influence of limb dominance on the incidence of knee flexor injuries
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11 (Svensson et al., 2016).
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16 The lack of influence of angular velocity on eccKF PT supports previous
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18 research (Westing et al., 1988). In contrast, Greig (2008) reported increased
19
20 eccKF PT with increasing angular velocity, attributed to lower torque values
21
22 at slow angular velocities compared with the present study. This might reflect
23
24 the calibre or training status of the players used. The increase in strength
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26 ratios with increased testing angular velocity is in agreement with previous
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28 research (Kellis, Arabatzl and Papadopoulos, 2003; De Ste Croix, Deighan
29
30 and Armstrong, 2007; Hewett, Myer and Zazulak, 2008) and attributed to
31
32 decreased knee extensor strength. Contrary findings have reported that the
33
34 DCR decreases with increased knee extension (Cohen et al. 2015; El-Ashker
35
36 et al. 2015), but these data were recorded closer to full extension and/or at
37
38 increased angular velocities.
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45 The current data recorded at high angular velocities and extended joint
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47 angles synonymous with lower limb injury risk demonstrate increased eccKF
48
49 PT and FR when compared to the conKE contractions. The observed
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51 discrepancies in the eccKF and conKE PT data also results in an increased
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53 DCR_{AST} recorded at high angular velocities. In contrast, the current conKE
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55 strength data was however identified as being greater than the eccKF data
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3 but only during slow ($60^{\circ}\cdot\text{s}^{-1}$) angular velocities and at flexed knee positions
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5 (70°), where knee flexor strain and knee ligamentous injury typically do not
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7 occur (Boden et al., 2000). It has previously been suggested that the risk of
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9 sustaining a knee flexor strain or ligamentous injury is greater during high
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11 velocity movements during increased knee extension (Woods et al. 2004;
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13 Hagglund, Walden, and Ekstrand, 2013; Kristianslund and Krosshaug, 2011)
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15 and, as such, the observed decrease in conKE strength at high angular
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17 velocities may therefore represent an aetiological risk factor. This is contrary
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19 to literature which suggests that increased knee extensor strength is a risk
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21 factor for ACL injury (Hewett et al. 2010) and knee flexor injury (Van Dyk et
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23 al. 2017).

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29 Both knee flexor and extensor musculature provide stability to the knee and
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31 ACL (Hughes and Watkins, 2006; Chmielewski et al., 2002), thus reducing
32
33 anterior shear force and ACL injury risk (Doorenbosch and Harlaar, 2003;
34
35 Kellis, Arabatzl and Papadopoulos, 2003). The knee extensor musculature
36
37 also helps to absorb shock and reduces strain during the initial ground
38
39 contact from dynamic movements (Podraza et al. 2010). Previous literature
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41 therefore suggests that players need to possess sufficiently developed and
42
43 balanced knee flexor and extensor musculature to help cope with the
44
45 demands of soccer-specific activity and reduce injury risk. The current data
46
47 suggests that an increased emphasis should be placed on the development
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49 of high velocity conKE strength at increased knee extension angles.
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3 In support of previous literature (Cohen et al., 2015; Kellis, Arabatzl and
4 Papadopoulos, 2003), the APT data recorded for the eccKF contractions
5 occurred at significantly more flexed positions at $270^{\circ}\cdot\text{s}^{-1}$ when compared to
6 $180^{\circ}\cdot\text{s}^{-1}$. These data therefore suggest that the current participants possess
7 reduced maximal strength capacity at extended knee positions, where knee
8 flexor injuries typically occur (Chumanov et al. 2012; Higashihara et al.
9 2015). This is further supported by the observed reduction in FR at increased
10 angular velocities.
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22 The importance of considering a range of joint angles and angular velocities
23 is apparent in the differences observed in the current APT data. Peak conKE
24 torque was achieved at $\sim 70^{\circ}$, whereas the eccKF torque was greatest at
25 $\sim 35^{\circ}$. The asynchrony observed in the APT data has implications for the
26 traditional calculation of strength ratios derived from force magnitude alone
27 (El-Ashker et al. 2015; Evangelidis et al. 2015), thus advocating the
28 calculation of DCR_{AST} . The DCR_{AST} data recorded at $270^{\circ}\cdot\text{s}^{-1}$ is comparable
29 to values previously reported by Cohen et al. (2015) and Evangelidis et al.
30 (2015). However, when comparing the DCR_{AST} at slow angular velocities, the
31 professional players tested in the current study elicited increased eccKF
32 strength when compared to their lesser standard counterparts (Cohen et al.
33 2015; Evangelidis et al. 2015), thus resulting in increased DCR_{AST} data. The
34 use of DCR_{AST} can therefore be used to differentiate between players of
35 different playing standards, and also enables the calculation of strength
36 ratios where ligamentous and muscular strain injuries are more likely to
37 occur (Boden et al., 2000). For example, in the current study, the observed
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3 reductions in conKE torque at high angular velocities and extended knee
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5 angles resulted in an increased DCR_{AST} .
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10 The use of isokinetic dynamometry imposes some inherent methodological
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12 issues, such as a restriction on obtaining isokinetic data close to full
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14 extension where injury risk is increased (Boden and Dean, 2000; Chumanov
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16 et al. 2012; Higashihara et al. 2015). The dynamometer constraints also do
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18 not allow data collection at angular velocities higher than those used in the
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20 current study and which might more closely represent the mechanisms of
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22 injury (Dowling et al. 2012; Nedergaard et al. 2014). Irrespective of the
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24 aforementioned limitations, isokinetic dynamometry and muscular strength
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26 testing is common practice in football. It is therefore important for sports
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28 scientists and fitness coaches alike to identify the limitations of equipment,
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30 but as identified in the current study, practitioners should attempt to develop
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32 methods to better utilise equipment to further inform practice.
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39 When considering that thigh musculature and knee ligamentous injuries
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41 typically occur in extended knee positions and at high angular velocities,
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43 practitioners should consider isokinetic testing protocols and metrics which
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45 consider these factors. The additional and novel metrics utilised in the
46
47 current study may also aid practitioners in determining strength deficits
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49 associated with ipsilateral and bilateral muscular asymmetries. Improved
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51 isokinetic screening practices should also be used to inform training
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53 paradigms, developing specificity in strength and power adaptations aligned
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55 with the specific demands of football. Given gender differences in specific
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3 injury incidences, such as ACL injury (Hewett et al., 2010); the same profiling
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5 could be applied to female players. Youth players might also be a focus, to
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7 further understand the longitudinal development of muscle imbalances in
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9 football players.
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11 12 13 14 **5.0 Conclusion**

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16 Professional football players were able to maintain eccKF strength over a
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18 range of angular velocities, but conKE strength decreased with angular
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20 velocity and increased knee extension angles. The influence of angular
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22 velocity has implications for the calculation of strength ratios and thus a
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24 range of angular velocities is advocated. The APT was achieved closer to
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26 knee extension in the knee extensors, and the lack of coincidence in the
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28 peak of the torque-angle curves advocates the use of AST. The FR was
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30 included as a novel isokinetic parameter which reflects the shape of the
31
32 strength curve. The eccKF musculature were better able to retain 85% of PT
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34 over a greater angular range, which might serve as a protective mechanism
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36 for injury. The interaction of joint angle and angular velocity on the thigh
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38 musculature relationship has implications in injury screening and athletic
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40 performance.
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Figure and Table Legends.

Figure 1. The influence of angular velocity on conKE (■) and eccKF (●) PT. * denotes significant difference between contraction types.

Figure 2. The influence of angular velocity on the FR (at 85% PT) in conKE (■) and eccKF (●). * denotes significant difference between contraction types.

Figure 3. The influence of angular velocity on AST for conKE (■) and eccKF (●) * denotes significant difference between limbs. # denotes significant difference between contraction types.