



**Isokinetic profiling of elite youth footballers: Informing selection of a practicable and efficacious isokinetic screening test.**

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**Abstract**

Isokinetic dynamometry represents the clinical gold standard for strength assessment but testing lack consensus. Elite youth *male* football players (n=28) completed 20 repetitions (analysed as 4 epochs) of eccentric knee flexor (eccKF) and concentric knee extensor (conKE) trials at 60, 180 and 270°·s<sup>-1</sup>, quantifying peak torque (PT) and functional range (FR). There was a significant (P < 0.001) main effect for fatigue and angular velocity in conKE PT; eccKF PT was *not significant* across epoch (P = 0.35) and velocity (P = 0.12) and a velocity x epoch interaction highlighted more repetitions were required to elicit fatigue as velocity increased. FR decreased with fatigue (P < 0.001) and velocity (P < 0.01) in conKE and eccKF, indicative of a narrowing of the strength curve. Clinical interpretation advocates an isokinetic test comprising at least 15 reps at a velocity ≥ 180°·s<sup>-1</sup> and analysis beyond the peak of the strength curve (PT) to inform clinical reasoning and individualised exercise prescription.

**Key Words:** Isokinetic Dynamometry, Professional Football, Youth, Screening

## Introduction

The primary concern for a sports medicine practitioner working in a professional football club academy is the medical welfare of the player. A philosophy of evidence-based-practice dictates that research is conducted in such a way as to optimise the practical implementation of sports medicine support for each player. However, the demands of the professional context dictate that conducting research is time limited, and data collection has to deliver maximal gains from minimal time investment from the player. Efficacy therefore becomes a primary concern, and isokinetic dynamometry for the assessment of strength as a primary and modifiable risk factor for muscular strain injury is one such example, and the focus of this study.

Musculature injuries are a significant problem in professional football (Ekstrand et al., 2013), with knee extensor (quadriceps) and knee flexor (hamstring) injury incidence ranging from 19 – 32% (Ekstrand et al., 2011) and 12 – 37% (Opar, Williams & Shield, 2012) respectively, with implications for senior professional (Woods et al., 2004; Ekstrand et al., 2011) and elite youth players (Cloke et al., 2012). This is exacerbated by a high (~ 17%, Ekstrand et al., 2011) rate of injury recurrence for both hamstring and quadricep injuries in elite senior and youth players (le Gall et al., 2006; Brooks et al., 2006; Ekstrand et al., 2016). Injury recurrence is typically associated with lengthier absences (Liu et al., 2012) and impacts upon the development of the young player. Muscular strength deficits (Askling et al., 2013; Croisier et al., 2008) and particularly reduced eccentric muscle strength (Nielsen & Yde, 1989; van Dyk et al., 2016), of the quadriceps and hamstrings are acknowledged as modifiable risk factors to reduce risk of myofascial, muscular or myotendinous junction and tendinous injuries.

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3 Isokinetic dynamometry is considered to be the gold standard clinical assessment of muscular  
4 strength (Stark et al., 2011) but the literature highlights varied and often arbitrary selection of  
5 repetitions and testing velocities (Askling et al., 2003; Small et al., 2010; van Dyk et al., 2017),  
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7 at times offering little functional relevance to the mechanism of injury (Greig & Siegler, 2009).  
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10 Previous studies have used three repetitions (Eustace, Page & Greig, 2017), ten (van Dyk et  
11 al., 2017), fifty (Sangnieer & Tourny-Chollet, 2007), and in excess of one-hundred repetitions  
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13 (Souron, Nosaka & Jubeau, 2018). Thigh musculature strength assessments are often  
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15 completed with isokinetic velocities ranging from  $60^{\circ}\cdot s^{-1}$  to  $180^{\circ}\cdot s^{-1}$  (Croisier et al., 2008;  
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17 Small et al., 2010; van Dyk et al., 2016), with other studies using  $300^{\circ}\cdot s^{-1}$  (Greig, 2008) to  
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19 better reflect sport-specific functional demands acknowledging angular velocities of  $\sim 400^{\circ}\cdot s^{-1}$   
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21 during change of direction tasks (Nedergaard, Kersting & Lake 2014). The previous literature  
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23 also highlights a lack of consensus in data analysis and the definition of outcome measures.  
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25 Anterior and posterior thigh musculature imbalances have previously been quantified using a  
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27 Hamstring:Quadriceps strength ratio (Aagard et al., 1998; Holcomb et al., 2007) defined as the  
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29 ratio between peak concentric torque (PT) of hamstring and quadriceps. The functional  
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31 strength ratio more appropriately considers the eccentric hamstring:concentric quadriceps  
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33 strength ratio (Willigenburg, McNally & Hewett, 2018), with a value closer to 1.0 considered  
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35 to reduce the risk of hamstring injury (Orchard et al., 1997; Holcomb et al., 2007), but is also  
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37 quantified using PT. The traditional use of peak torques and control ratios has more recently  
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39 been usurped by a broader consideration of the strength curve, including angle-specific torque  
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41 and functional range (Eustace et al., 2017).  
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54 The clinical gold standard must be applicable in a way that suits the demands of a  
55 professional football club. Anecdotally practitioners have expressed concern over the time  
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57 taken, the risk of injury, and the clinical value in isokinetic assessments. This helped to  
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3 shape a desire for a single data collection trial, and a data analysis process that would directly  
4 inform training interventions and would be transferable across medical departments  
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6 (physiotherapy, sports science, strength and conditioning). The aim of this study was to  
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8 utilise a battery of isokinetic testing to inform prescription of a single trial for subsequent  
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10 player profiling within a professional football club. Whilst previous studies highlight the lack  
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12 of power in predicting injury (Green et al., 2017; van Dyk et al., 2016, 2017), this negates the  
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14 purpose of assessment which is to inform (p)rehabilitation rather than to predict injury. **The  
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16 present study considers elite youth players, with age acknowledged as a risk factor for thigh  
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18 musculature injuries. It has been suggested that elite adolescent athletes between the ages of  
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20 16 and 18, as well as periods after adolescent growth demonstrate a greater risk of thigh  
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22 musculature injury (Cloke et al., 2012; van der Sluis, 2015).**  
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## 30 **METHODS**

### 31 *Participants*

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33 Twenty-eight elite youth **male** players (Age:  $16.7 \pm 1.3$  years; height:  $179.2 \pm 11.2$  cm; Mass:  
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35  $72.4 \pm 8.6$  kg) from the same club in the English Football League Championship were recruited  
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37 to participate in this study. Inclusion criteria required the participants to have received no  
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39 quadriceps or hamstrings injuries within the previous twelve weeks, be contracted to the  
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41 football club, be aged between 16 and 19, and be completing a weekly training volume of  $\sim 14$   
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43 hour week<sup>-1</sup>. Prior to each experimental condition, all participants were required to complete a  
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45 health screening procedure comprising a health, physical activity and pre-exercise control  
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47 questionnaire. All players provided written consent and were made aware that data would  
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49 remain anonymised and would not affect their standing within the team. Parent/guardian  
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51 consent was also obtained for the youth players aged below 18 years. Ethical consent was  
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provided by Edge Hill University's research ethics committee and in accordance with the Helsinki declaration.

### *Experimental Procedures*

Players completed a single experimental trial, and in attempt to reduce the influence of residual fatigue, as identified in the PPI consultations, a 48-hour rest-period from exercise was factored into the player's weekly macrocycle. Pre-testing the dynamometer was calibrated in accordance with manufacturer guidelines whilst participants completed a standardised 5-minute warm up on a stationary cycle ergometer (Monark, 824E, Sweden) at 60 W (Eustace et al., 2017) and were given opportunity to complete self-directed mobilisations and stretching. Three trial repetitions were completed prior to each experimental trial, with an experimental trial comprising 20 maximal effort repetitions of dominant limb isokinetic (Biodex Medical Systems, System 2, Shirley, New York, USA) strength assessments at angular velocities of 180, 270, and 60°·s<sup>-1</sup>. This testing order was designed to minimise the impact of the slowest 60°·s<sup>-1</sup> trial, associated with greater time under tension, on subsequent trials (Greig, 2008). Concentric knee extensor (conKE) and eccentric knee flexor (eccKF) trials were completed in randomised order. Passive knee flexion performed at 60°·s<sup>-1</sup> separated each repetition, with a rest period of 10 minutes interspersing each set. Verbal feedback was providing solely during the familiarisation trial with no feedback provided during the experimental trial. The isokinetic dynamometer was set up specific to each individual with the crank axis aligned with the axis of rotation of the knee and anatomically referenced to 90° of knee flexion. Data collection reflected the full range of motion for each player, with a gravity correction applied with 0° of knee flexion. The lever arm cuff securely fastened around the ankle; approximately 5cm proximal to the malleolus (Greig, 2008; Eustace, Page & Greig, 2017).

### *Data Analysis*

Each 20-repetition set was sub-divided into four epochs of five repetitions and the peak repetition of each epoch was identified and used for data analysis (van Dyk et al., 2016). Analysis was restricted to isokinetic data, defined by applying a 1% cut-off to the predetermined angular velocity. The peak torque (PT) was identified for each rep, with functional range (FR) defined as the range over which 85% of PT was maintained (Eustace et al., 2017). PT values recorded from the eccKF and conKE assessments were used to calculate the traditional dynamic control ratio (DCR) at each testing velocity.

### *Statistical Analyses*

Statistical analysis was conducted using PASW Statistics Editor 24.0 for windows (SPSS Inc., Chicago, IL USA). Before parametric analysis, the assumptions of normality of the residual values was assessed using a Shapiro-Wilk test, with significance set at  $P \leq 0.05$ . Subsequently, a repeated measures general linear model was used to investigate main effects for testing velocity, epoch, and velocity  $\times$  epoch interactions in each parameter. Where appropriate, post hoc pairwise comparisons with a Bonferonni correction were applied. For all significant interactions, 95% confidence intervals (CI) and observed power are reported in conjunction with the frequentist statistical approach. All data was reported as mean  $\pm$  SD.

## **Results**

### *Peak Torque*

Figure 1 summarises the influence of angular velocity and epoch on peak torque. There was a significant ( $P < 0.001$ ; Observed Power = 0.99) main effect for velocity in conKE, with PT decreasing as velocity increased. There was no significant ( $P = 0.12$ ) main effect for velocity in EccKF, with PT maintained at  $\sim 126$  Nm.

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3 There was also a significant ( $P < 0.001$ ; **Observed Power = 0.98**) main effect for epoch in  
4 conKE with PT decreasing with prolonged exercise duration. There was no significant ( $P =$   
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6 0.35) main effect for epoch in eccKF PT.  
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17 Table 1 summarises the influence of contraction modality, angular velocity and epoch on PT.  
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19 The general linear model (GLM) identified a significant epoch  $\times$  velocity conKE interaction ( $P$   
20  $< 0.001$ ; **Observed Power = 0.97**) with significantly ( $P \leq 0.01$ ) higher values recorded for  $60^\circ \cdot s^{-1}$   
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22 <sup>1</sup> when compared to all other velocities in each epoch, **whilst  $180^\circ \cdot s^{-1}$  displayed significantly**  
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24 **higher values ( $P < 0.01$ ) when compared to  $270^\circ \cdot s^{-1}$ .** Furthermore, an epoch  $\times$  velocity  
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26 interaction was also identified for eccKF PT ( $P < 0.001$ ; **Observed Power = 0.75**) with  
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28 significant differences highlighted in epoch 2 ( $P \leq 0.01$ ), epoch 3 ( $P \leq 0.01$ ) and epoch 4 ( $P \leq$   
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### 43 *Functional Range*

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45 Figure 2 summarises the influence of angular velocity and epoch on functional range. There  
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47 was a significant main effect for angular velocity in conKE FR ( $P < 0.001$ ; **Observed Power =**  
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49 **0.99**) with a significantly lower FR at  $270^\circ \cdot s^{-1}$  ( $18.09 \pm 4.25^\circ$ ) when compared to  $60^\circ \cdot s^{-1}$  ( $20.20$   
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51  $\pm 5.67^\circ$ ;  $P = 0.01$ ; 95% CI = 0.40 to 3.81). A significant ( $P < 0.01$ ; **Observed Power = 0.99**)  
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53 main effect for velocity in eccKF FR was also identified, with significantly lower values at  
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55  $270^\circ \cdot s^{-1}$  ( $18.48 \pm 9.15^\circ$ ) compared to  $60^\circ \cdot s^{-1}$  ( $24.23 \pm 7.14^\circ$ ;  $P = 0.03$ ; 95% CI = -10.80 to -  
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57 0.69) and  $180^\circ \cdot s^{-1}$  ( $21.66 \pm 10.25^\circ$ ;  $P = 0.01$ ; 95% CI = -5.95 to -0.42).  
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6 There was also a significant main effect ( $P < 0.001$ ; **Observed Power = 0.85**) for epoch in  
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8 conKE with significantly lower functional range during epoch 4 ( $14.53 \pm 3.29^\circ$ ) when  
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10 compared to epoch 1 ( $20.21 \pm 5.23^\circ$ ; 95% CI = -0.17 to -2.20), epoch 2 ( $21.58 \pm 5.33$ ; 95%  
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12 CI = -11.89 to -2.22) and epoch 3 ( $20.72 \pm 5.89$ ; 95% CI = -10.48 to -1.90). Significant velocity  
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14  $x$  epoch interactions are identified ( $P < 0.001$ ; **Observed Power = 0.98**) for conKE FR in epoch  
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16 3 only, with significantly lower functional ranges highlighted at  $270^\circ \cdot s^{-1}$  ( $13.05 \pm 2.94^\circ$ ) when  
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18 compared to  $60^\circ \cdot s^{-1}$  ( $24.74 \pm 6.35^\circ$ ;  $P < 0.001$ ; 95% CI = -17.81 to -5.56) and  $180^\circ \cdot s^{-1}$  ( $24.37$   
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20  $\pm 9.97^\circ$ ;  $P < 0.001$ ; 95% CI = -16.60 to -6.03).  
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26 A similar trend was observed for eccKF FR, with a significant main effect for epoch ( $P < 0.001$ ;  
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28 **Observed Power = 0.98**) highlighting significantly lower values at epoch 4 ( $10.72 \pm 2.07^\circ$ )  
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30 when compared to epoch 1 ( $28.86 \pm 4.71^\circ$ ;  $P < 0.001$ ; 95% CI = -25.98 to -10.30), epoch 2  
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32 ( $24.33 \pm 5.21^\circ$ ;  $P = 0.01$ ; 95% CI = -24.44 to -2.79) and epoch 3 ( $21.92 \pm 4.98^\circ$ ;  $P = 0.02$ ; 95%  
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34 CI = -21.09 to -1.30). No significant ( $P = 0.56$ ) eccKF FR epoch  $x$  velocity interactions were  
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36 identified.  
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\*\* Insert Figure 2 near here \*\*

#### *Dynamic Control Ratio (DCR)*

Table 2 highlights a significant main effect for DCR PT<sub>60</sub> ( $P < 0.001$ ; **Observed Power = 0.98**) and epoch, with post-hoc Bonferonni correction factors highlighting a temporal fatigue effect ( $P < 0.001$ ; **Observed Power = 0.91**) with significantly increased values observed during epoch 1 ( $1.61 \pm 0.34$ ), when compared to all subsequent variables. No significant epoch main effects were identified for DCR PT<sub>180</sub> ( $P = 0.31$ ) nor DCR PT<sub>270</sub> ( $P = 0.64$ ).

\*\* Insert Table 2 near here \*\*

## DISCUSSION

The primary aim of this study was to prospectively develop an optimal isokinetic screening trial based on analysis of an isokinetic test on elite youth football players. In the clinical context the optimal screening trial would be time and resource effective whilst offering the necessary analysis to inform interventions.

### *Practical implications for isokinetic data collection*

A primary consideration in isokinetic assessment is the testing velocity (Greig, 2008). There was a significant main effect for velocity in conKE peak torque, as expected given the classic force-velocity relationship of muscle and supporting previous observations of reduced conKE strength with increasing velocity (Greig, 2008; Eustace et al., 2017). In contrast, eccKF peak torque is maintained with increasing velocity, and therefore as angular velocity increased the quadriceps dominance apparent at slow velocities was reduced. The conKE and eccKF torque-velocity curves did not cross as observed by Eustace et al (2019) in senior professional players, where the eccentric knee flexors became dominant at velocities greater than approximately  $200^{\circ}\cdot\text{s}^{-1}$ . This might reflect the relative training status of the samples, with the youth players used in the current study not generating the same magnitude of peak torques observed by Eustace et al (2017). The lack of a main effect for velocity in eccKF would suggest that angular velocity is not **absolutely paramount when** developing a screening trial, where perceived safety of slower velocities might be preferable to the arguably more functionally relevant velocities approaching the limits of isokinetic dynamometers. However, testing velocity is only part of the clinical reasoning process in data collection and research design.

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3 In the current study data collection included 20-repetitions, subsequently sub-divided into four  
4 epochs. There was a significant main effect for epoch (with the data pooled for all velocities)  
5 in conKE but not in eccKF, suggesting that the concentric knee flexors exhibited an acute  
6 within-set fatigue effect. This observation might reflect a specific response to modality,  
7 differentiating the mechanism of concentric and eccentric muscular contractions.  
8 Alternatively, this finding might be indicative of a lack of strength endurance in concentric  
9 knee flexors, which is not apparent in the eccentric knee flexors. Relative adaptations in conKE  
10 strength and eccKF strength endurance in these youth players might reflect their training  
11 history, but might also identify specific training needs. Whilst strength is widely acknowledged  
12 as a primary risk factor for muscular strain injury (Croisier et al., 2008; van Dyk et al., 2016),  
13 the physical demands of football and epidemiological observations of increased injury risk  
14 during the latter stages of match-play also stress the importance of strength endurance. The  
15 resistance of eccKF strength to a 20-repetition set might reflect a history of adaptation to  
16 intermittent running, whereas the decline over 20 repetitions in conKE might reflect a gym-  
17 based strength emphasis defined by lower repetitions.

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40 With the data considered at each testing velocity discretely, the velocity  $\times$  epoch interaction in  
41 eccKF peak torque highlighted that a fatigue-induced inflection point in peak torque shifted  
42 towards the latter parts of the set as angular velocity increased. This might represent the  
43 muscular work done per repetition, with the increase in angular velocity over the same range  
44 eliciting a lower demand and therefore enabling more repetitions before the onset of acute  
45 fatigue. Therefore, whilst testing velocity does not influence the magnitude of peak torque in  
46 eccentric hamstrings, there is a velocity  $\times$  rep interaction that should inform data collection. In  
47 this respect we advocate a higher testing velocity within the constraints of the equipment, since  
48 a higher velocity would offer greater functional specificity to the mechanism of injury (Greig  
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3 & Siegler, 2009; Eustace et al., 2017), without increasing the risk of injury perceived by some  
4 practitioners. At this higher angular velocity we would advocate 15-20 repetitions in order to  
5 induce a fatigue effect. Differentiating deficits in strength and/or strength endurance would  
6 better inform personalised interventions and exercise prescription.  
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#### 14 *Practical implications for isokinetic data analysis*

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16 The 20-repetition set would enable the calculation of a fatigue index, further informing the  
17 training needs of the player beyond maximum strength. The inclusion of functional range in  
18 data analysis is designed to extend consideration of the strength curve beyond the single  
19 maxima in peak torque that is typically presented in the literature. Considering strength as a  
20 function of velocity and joint angle helps to inform individualised training interventions,  
21 particularly when considering strength deficits are the aetiological risk (Croisier et al., 2008;  
22 van Dyk et al., 2016). The main effect for velocity observed in functional range is partly  
23 influenced by a narrowing of the isokinetic range and should therefore be treated with caution,  
24 but the influence of epoch also suggests a narrowing of the strength curve. This has  
25 implications for injury, since the demands of the sport require knee range of motion beyond  
26 the angle of peak torque, and the mechanism of injury can be diverse.  
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44 The dissociation between peak torque and functional range in their sensitivity to testing  
45 velocity and repetition volume adds value to this metric, in contrast to work done for example  
46 which is highly correlated with peak torque (Dvir, 2014). Whilst in conKE the player reduced  
47 peak torque but was able to retain functional range for more reps, in eccKF the player  
48 maintained peak torque but suffered a progressive reduction in functional range. This  
49 differential between peak and width of the curve has implications for injury risk, and  
50 subsequently for exercise prescription. Angle-match torque data is an additional means of  
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3 considering specifics of the strength curve (Eustace et al., 2017), but at the higher testing  
4 velocities the isokinetic phase is reduced. In the current study the isokinetic phase at the highest  
5 angular velocities did not offer data beyond approximately 35° of knee flexion **in this sample**  
6 **of elite youth male footballers**. We would therefore advocate angle-matched data where there  
7 was a specific rationale, for example when monitoring rehabilitation of an injured player. The  
8 lack of isokinetic **torque data** at high velocities might be **supplemented by isometric testing**  
9 **where appropriate**.

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12 Care should be taken in generalising these findings beyond the specific sample and testing  
13 protocol used. The players were elite male youth footballers **with implications for their training**  
14 **status and history**, injury free, and tested in a non-fatigued state. The optimum isokinetic screen  
15 might therefore differ in other samples, such as senior or female players, and in other sports  
16 reflecting specificity in adaptation. The influence of previous injury on the response to a high  
17 velocity and high volume test also warrants consideration. **Similarly, the testing protocol of**  
18 **twenty repetitions was used to reflect the strength endurance training regime of these players,**  
19 **and future research might consider more repetitions and/or more sets, acknowledging a**  
20 **potential lag in response to fatigue**.

## 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 **Conclusion**

46 Isokinetic profiling is widely acknowledged as the gold standard measure of strength (Eustace  
47 et al., 2017; van Dyk et al., 2017; Buckthorpe et al., 2018) but should be considered as a means  
48 of informing needs-based interventions, and not as a predictor of injury (Green et al., 2018).  
49 Strength imbalances should be considered as an internal, modifiable risk factor, but many  
50 complex interactions may then precede an injurious event. In data collection we advocate high  
51 velocity testing  $\geq 180^{\circ}\cdot\text{s}^{-1}$  to provide greater functional relevance to the common mechanisms  
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3 of injury, to reflect the potential cross-over defined by ipsi-lateral strength symmetry, and to  
4 reduce the total amount of work done per repetition. Correspondingly, we advocate a high  
5 number  $\geq 15$  reps at this velocity to induce an acute inflection and to enable calculation of  
6 fatigue indices and needs in strength endurance. In analysis we advocate investigation away  
7 from the single maxima of peak torque and towards a broader consideration of the strength  
8 curve. Identifying personalised needs defining strength deficits as a function of velocity, joint  
9 angle and repetition volume provides a more comprehensive profile upon which to develop  
10 evidence-based clinical exercise prescription.  
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27 Team Medicine) in enabling this project to be completed.  
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38 **Declaration of interest statement:** No competing interests declared.  
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### Legend to Figures

Figure 1: The influence of (a) angular velocity and (b) epoch on conKE and eccKF PT.

\* denotes a significant difference within the same contraction mode

Figure 2: The influence of (a) angular velocity and (b) epoch on conKE and eccKF FR.

\* denotes a significant main effect with  $60^{\circ}\cdot s^{-1}$  within contraction type, # denotes a significant main effect with epoch 4 irrespective of contraction type

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Table 1: The influence of angular velocity, contraction type and epoch on PT

Angular Velocity ( $^{\circ}\cdot\text{s}^{-1}$ )	Contraction Type	Epoch 1 (5 repetitions)	Epoch 2 (10 repetitions)	Epoch 3 (15 repetitions)	Epoch 4 (20 repetitions)	
60	eccKF	$122.27 \pm 12.87$	$116.26 \pm 21.82$ *	$124.10 \pm 30.73$ ~	$137.14 \pm 27.06$ ~	
			CI = -43 to -2	CI = -35 to -6	CI = 9 to 22	
			P = 0.03	P < 0.01	P < 0.01	
	conKE	$202.98 \pm 25.18$ *	$185.06 \pm 24.40$ ~	$171.49 \pm 25.56$ ~	$158.90 \pm 28.57$ *	
		CI = 11 to 24	CI = 0.2 to 33	CI = 1 to 12	CI = 4 to 11	
		P < 0.001	P = 0.05	P = 0.02	P < 0.001	
180	eccKF	$124.88 \pm 21.66$	$139.40 \pm 19.39$ ~	$119.18 \pm 20.67$ ~	$130.41 \pm 19.20$	
		conKE	$150.80 \pm 13.73$ ~	$142.29 \pm 15.53$ ~	$135.22 \pm 15.13$ ~	$128.42 \pm 13.76$ ~
			CI = 6 to 21	CI = 4 to 13	CI = -15 to -3	95 CI = 1 to 7
	P < 0.001		P < 0.001	P < 0.01	P = 0.02	
	270	eccKF	$119.00 \pm 15.06$	$125.76 \pm 17.01$ *	$145.06 \pm 18.19$ *	$116.12 \pm 17.75$
				CI = -22 to -4	CI = 14 to 38	
			P < 0.001	P < 0.001		
conKE		$137.27 \pm 14.42$ #	$129.78 \pm 14.71$ #	$121.84 \pm 17.07$ #	$117.92 \pm 17.96$ #	
		CI = -42 to -21	CI = 42 to 67	CI = 36 to 63	95 CI = -17 to -7	
		P < 0.001	P < 0.001	P < 0.001	P < 0.001	

# denotes a significant epoch\*velocity interaction with  $60^{\circ}\cdot\text{s}^{-1}$ ; \*denotes a significant epoch\*velocity interaction with  $180^{\circ}\cdot\text{s}^{-1}$ ; ~ denotes a significant epoch\*velocity interaction with 270;

Table 2: The influence of epoch and angular velocity on Dynamic Control Ratio PT (DCR PT)

DCR PT	Epoch 1	Epoch 2	Epoch 3	Epoch 4
60	1.61 ± 0.34	1.45 ± 0.35 *	1.41 ± 0.43 *	1.36 ± 0.44 *
		CI = 0.2 to 0.3	CI = 0.01 to 0.40	CI = 0.03 to 0.50
		P = 0.02	P = 0.05	P = 0.02
180	1.05 ± 0.17	1.10 ± 0.21	1.08 ± 0.20	1.05 ± 0.20
270	0.92 ± 0.16	0.92 ± 0.17	0.89 ± 0.21	0.93 ± 0.25

\* Denotes a significant difference with Epoch 1

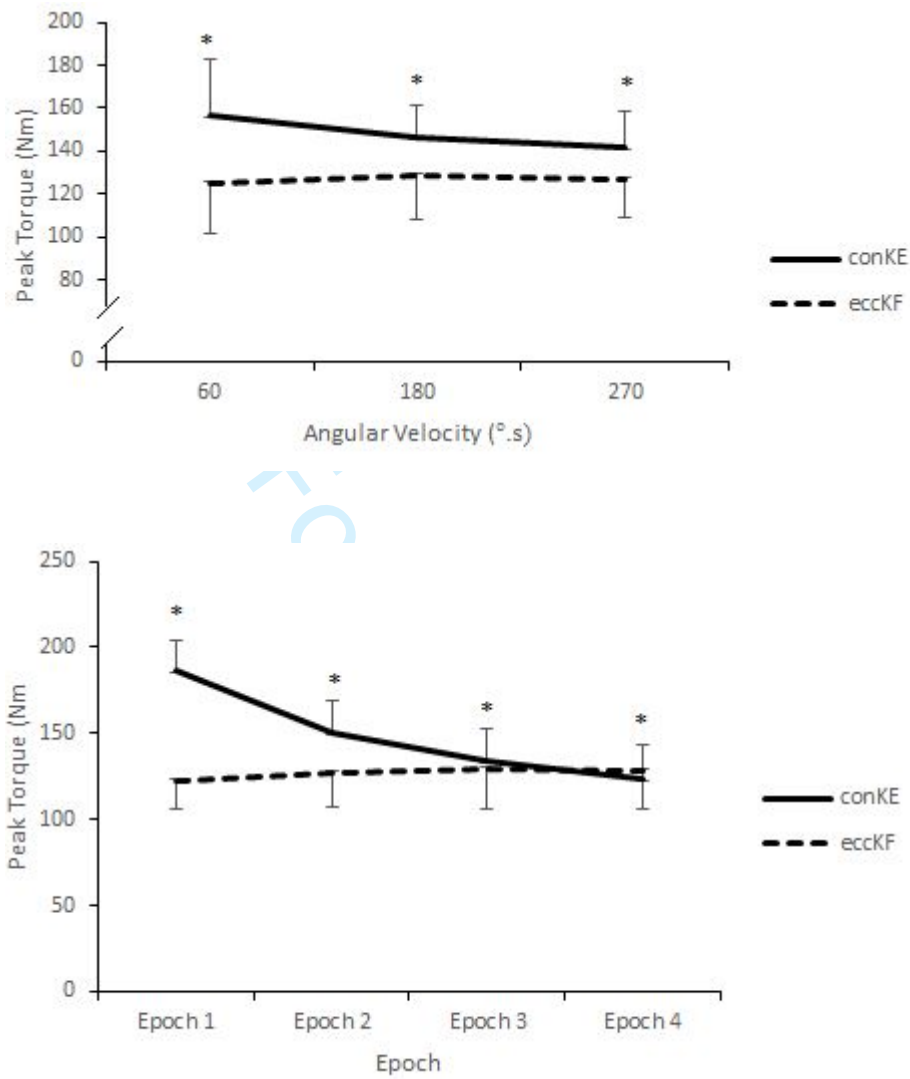


Figure 1: The influence of (a) angular velocity and (b) epoch on conKE and eccKF PT.

\* denotes a significant difference within the same contraction mode

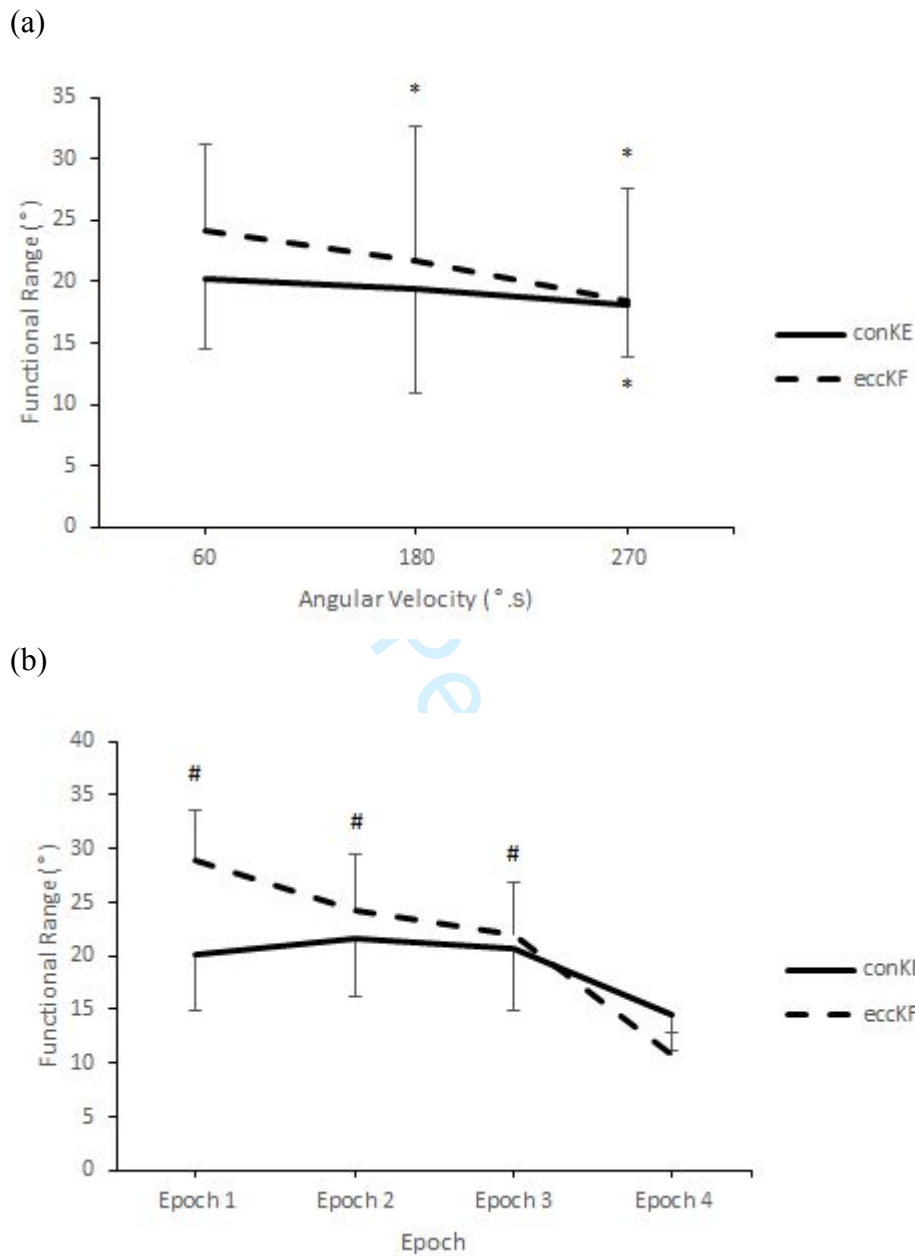


Figure 2: The influence of (a) angular velocity and (b) epoch on conKE and eccKF FR.

\* denotes a significant main effect with  $60^{\circ}\cdot s^{-1}$  within contraction type, # denotes a significant main effect with epoch 4 irrespective of contraction type