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1 **Dissociation between fatigued power output and traditional peak torque for isokinetic hamstring: quadriceps**
2 **ratios in professional soccer players**

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19 Running title: The new power output H:Q$_{fatigued}$ ratio

2

Abstract

21 **Background:** Muscle strength imbalance assessment (e.g. hamstring-to-quadriceps ratio, H:Q) using traditional peak

22 torque isokinetic measurements has been shown to be a weak risk factor predictor of future lower-limb injuries (e.g.

23 hamstring strain and anterior cruciate ligament tear). In soccer, power-related tasks are commonplace and injuries are

24 most likely to occur during fatigued high-velocity actions. Thus, it is reasonable to that calculating H:Q using power

25 output may serve as an alternative to traditional peak torque-based H:Q. **Aims:** We aimed to investigate the relationship

26 of isokinetic H:Q calculated from traditional peak torque and power output during non-fatigue and fatigue conditions.

27 **Methods:** Seventy-nine professional soccer players (25.6 ± 4.9 years old; 78.7 ± 8.1 kg; 179.4 ± 6.7 cm) performed

28 concentric knee extension-flexion contractions at $60^{\circ} \cdot s^{-1}$ (5 repetitions) and $300^{\circ} \cdot s^{-1}$ (30 repetitions, fatigue trial).

29 Traditional peak torque H:Q was calculated using the highest torque obtained during five repetitions at $60^{\circ} \cdot s^{-1}$. Power

30 output H:Q$_{non-fatigued}$ was calculated using the average from the 2nd, 3rd and 4th repetitions, and power output H:Q$_{fatigued}$

31 was obtained as the average of the power output of the last 3 repetitions of the fatigue trial. **Results:** Weak ($r_s = 0.27$) and

32 moderate ($r_s = 0.49$) correlations were found between traditional peak torque and power output H:Q$_{fatigued}$, and traditional

33 peak torque and power output H:Q$_{non-fatigued}$, respectively. **Conclusion:** The present data suggested that power H:Q differ

34 from traditional H:Q, particularly during fatigue in professional soccer players, which warrants further investigation on

35 the potential use of power output H:Q ratios for injury prediction.

36 **Keywords:** muscle strength imbalance; isokinetic strength testing; fatigue; muscle power; football

Conflict of interest statement

None to declare.

Data availability

Raw data will be available for publisher as requested.

Data transparency

All authors make sure that all data and materials as well as software application or custom code support their published claims and comply with field standards.

Ethics approval

This study was approved by the Institutional Ethics in Research Committee (protocol number: 2.903.811).

Consent to participate

All volunteers agreed to participate through a consent term.

Consent for publication

The authors consent with publication in the Sport Sciences for Health.

Abbreviations:

H:Q: Hamstring to quadriceps ratio

Power output H:Q$_{non\text{-}fatigued}$: Power output H:Q assessed without fatigue

Power output H:Q$_{fatigued}$: Power output H:Q in the fatigued condition

72   **Introduction**

73   Power-related tasks such as jumping, and sprinting are essential for soccer performance (Maestroni, 2018). Over

74   the past fifteen years, high-intensity running has increased about 50% in professional soccer matches with elite players

75   increasing the number and distance of sprints by ~35 and 85%, respectively (Barnes et al., 2014). Unfortunately, the

76   incidence of lower-limb injuries such as hamstring strain and knee ligament tears has also been reported (Ekstrand et al.,

77   2011; Erickson et al., 2013). For example, an increase of ~4% and ~6% per year has been reported for hamstring strain

78   and knee ligament tears, respectively (Ekstrand et al., 2011; Rekik et al., 2018), which highlights the need for a more

79   comprehensive injury prevention program and screening strategies (Oakley et al., 2018; Zambaldi et al., 2017).

80   Several approaches have been employed to stratify injury risk and help decision-making about return-to-play in

81   soccer, with isokinetic testing being a common choice (McCall et al., 2014). However, studies by van Dyk et al. (2016),

82   Green et al. (2018) and Dauty et al. (2018) have recently highlighted the low predictive potential value for hamstring and

83   knee ligament tears injuries of traditional isokinetic parameters in soccer players (e.g. peak torque-based hamstring to

84   quadriceps ratio – H:Q). Moreover, since hamstring strain and knee injuries are most likely to occur during high-velocity

85   tasks (Chumanov et al., 2011; Johnston et al., 2018) or in conditions of neuromuscular fatigue (Ekstrand et al., 2011), the

86   traditional peak torque parameters taken from isokinetic tests performed at relatively slow angular velocity (e.g., $60°·s^{-1}$)

87   may not reflect the demands associated with elite soccer performance. As such, new and more ecological approaches are

88   needed to improve injury prediction, prevention, and inform return-to-play decision for professional athletes.

89   Quantification of H:Q based on alternative isokinetic parameters, such as the total work produced in concentric

90   and eccentric knee actions (Minozzo et al., 2018), and during fatigue conditions (Pinto et al., 2017; Lord, Ma'ayah &

91   Blazevich, 2018) have been shown to differ from peak torque-based H:Q. Accordingly, assessment of isokinetic power

92   output may be an alternative to peak torque for H:Q calculation, as it may reflect more closely the demands of powerful

93   tasks in elite sports (Maestroni, 2018). In addition, the ability to generate force at higher angular speed seems to be more

94   affected by fatigue than peak torque (Buckthorpe et al., 2014; Grazioli et al., 2019), which could be associated to increased

95   risk of injury during power-related tasks. Hence, peak power output derived from isokinetic dynamometry tests (i.e.,

96   product of moment and angular velocity (Iossifidou and Baltzopoulos, 2000)) may be an alternative to traditional H:Q

97   ratios to inform coaches and players about injury risk. However, the relationship between power output and peak torque

98   values on H:Q ratio calculations, as well as the influence of fatigue on such ratios, has been overlooked.

99   Thus, the purpose of the present study was to investigate the relationship of isokinetic H:Q calculated from

100   traditional peak torque and power output during non-fatigue and fatigue conditions. Our hypothesis is that H:Q scores

101   calculated using power output represent a distinct phenomena compared to traditional peak torque H:Q calculations and,

102   hence, will result in distinct and unrelated scores in each athlete.

103   **Materials and methods**

104   *Participants*

105   Seventy-nine male professional soccer players (25.6 ± 4.9 years old; 78.7 ± 8.1 kg; 179.4 ± 6.7 cm) from three

106   soccer teams playing at national and international levels volunteered for this study. All players were asymptomatic and

107   free from injuries and provided written consent to this study. Tests were performed in both lower limbs during pre-season

108   as part of the players' screening procedure, and data was then retrieved from laboratory database. The regional research

109   ethical committee approved this study (approval number: 2.903.811).

110   *Isokinetic Protocols*

111   Maximal isokinetic knee extension and flexion concentric contractions were performed through a 90º range of
112   motion (0º = full extension) using an isokinetic dynamometer (Cybex Norm, NY, USA). The testing protocol was
113   preceded by a warm-up on a cycle ergometer at comfortable pace for five minutes (Movement Technology, BM2700, SP,
114   Brazil). After that, participants were positioned sitting upright on the dynamometer chair. The lateral epicondyle of the
115   limb was aligned with the dynamometer axis of rotation, and the machine's lever arm was attached to the lower limb, 2
116   cm above the lateral malleolus. Straps were positioned across the participants' thigh, hip and chest to minimize additional
117   movement (Pinto et al., 2017).

118   Prior to testing, the participants performed a specific warm-up consisting of 10 submaximal isokinetic knee
119   extension-flexion repetitions at $120º \cdot s^{-1}$. After warm-up, participants performed 5 maximal concentric knee extension-
120   flexion contractions at $60º.s{-1}$ (van Dyk et al. 2016) for baseline peak torque assessment. The power output under non-
121   fatigue and fatigue conditions was assessed during a fatigue trial, which trial consisted of 30 maximal concentric knee
122   extension-flexion repetitions at $300º \cdot s^{-1}$, similar to previous studies (Pinto et al., 2017). Athletes were instructed to "push
123   and pull as hard and fast as possible" (Sahaly et al., 2001) and verbal encouragement was given throughout the protocols.
124   There was 90 s of rest between the peak torque and the fatigue trials. Participants were familiar with all testing procedures
125   due to frequent screening routines prior to and during the season. Raw data was exported from the dynamometer software
126   (HUMAC V. 12.17.0, MA, USA) to a personal computer after gravity correction, and peak values of torque and power
127   from both lower limbs were used for further analysis.

128   *Isokinetic protocol analysis*

129   With higher angular velocities ($> 180º \cdot s^{-1}$), load range phase is shorter and peak moment is likely to occur during
130   the acceleration or deceleration period (Iossifidou and Baltzopoulos, 1996). In this case, moment and angular velocity
131   values are used to calculate power output at high angular velocities (Iossifidou and Baltzopoulos, 2000). Therefore,
132   optimal angular velocities were chosen for each selected variable (i.e., knee extension and flexion peak torque was
133   measured at $60º \cdot s^{-1}$, while peak power was assessed at $300º \cdot s^{-1}$). Individual H:Q was calculated dividing concentric knee
134   flexion by concentric knee extension performance (i.e. using both peak torque or power, as detailed below).

135   Traditional peak torque H:Q was calculated using the highest torque obtained during five repetitions performed
136   at $60º \cdot s^{-1}$. Power output H:Q assessed without fatigue (Power output $H:Q_{non-fatigued}$) was calculated using the average power
137   output from the 2nd, 3rd and 4th repetitions of the fatigue trial. The 1st repetition was discarded to minimize potential
138   artefacts related to the onset of contraction. Power output H:Q underfatigued condition ($H:Q_{fatigued}$) was obtained as the
139   average power output of the last 3 repetitions (i.e. 28th, 29th and 30th repetitions) of the fatigue trial.

140   *Statistical analysis*

141   Data normality was assessed using the Shapiro-Wilk test, and descriptive values are shown as mean ± standard
142   deviation (SD) and 95% confidence intervals (95% CI). Independent T-tests were used to compare right and left lower
143   limbs isokinetic values. Since no difference in performance parameters was observed between right and left limb data,
144   both limbs of participants were considered for analysis a single dataset. Paired sample T-test was performed to examine
145   changes in isokinetic performance with the fatigue protocol. Bland-Altman analysis and limits of agreement (±1.96 SDs
146   or the 95% CI) were used to illustrate agreement between measurements and identify bias. A linear regression was used
147   to test for proportional bias. Furthermore, the Spearman's rank-order correlation was employed to assess the relationship

148 between H:Q within the cohort. Finally, traditional peak torque H:Q values were used as an ordinal variable to define

149 quartiles, and one-way analysis of variance (ANOVA) with Tukey's *post hoc* were used to compare the power output

150 H:Qfatigued values among quartiles. The level of significance (α) was set at 0.05 and all statistical procedures were

151 performed using the Statistical Package for Social Science (SPSS) version 20.0 (IBM SPSS Inc., IL, USA).

152 **Results**

153 *Isokinetic tests performance*

154 No differences were found at baseline between limbs for knee extension (right = 240.6 ± 39.6; left = 240.9 ±

155 42.6 N·m, P = 0.968) and knee flexion peak torque (right = 148.5 ± 29.5; left = 144.9 ± 28.9 N·m, P = 0.440). Similarly,

156 power output did not differ between the right and left limbs during knee extension (right = 354.2 ± 58.9; left = 355.6 ±

157 61.0 W, P = 0.327) and knee flexion (right = 242.6 ± 52.4; left = 233.5 ± 49.9 W, P = 0.479). Likewise, no difference

158 between limbs power output during fatigue was observed for knee extension (right = 220.6 ± 35.5; left = 220.3 ± 34.5 W,

159 P = 0.811) and flexion (right = 124.5 ± 35.6; left = 121.1 ± 30.4 W, P = 0.402). Hence, further analyses were conducted

160 using the whole sample (n = 158 lower limbs). Table 1 describes the comparisons made between different conditions. By

161 the end of the fatigue protocol, knee extension power output was reduced by 151.3 W (95% CI: -158.6 to -144.0; P <

162 0.001) and knee flexion power output was reduced by 130.6 W (95% CI: -136.8 to -124.4; P < 0.001). Power output H:Q

163 reduced from an average of 0.68 to 0.56 (95% CI: -0.15 to -0.11; P < 0.001) with fatigue.

164 Insert Table 1 here

165 *Agreement and correlation between traditional peak torque and power H:Q ratios*

166 Bland-Altman plots showed high agreement between traditional peak torque and both power output H:Qnon-fatigued

167 and power output H:Qfatigued, while a significant proportional bias (t= 2.31, P= 0.022; Figure 1 panel A) and a non-

168 significant systematic trend (t=0.04, P=0.969; Figure 1 panel B) were found, respectively. Furthermore, moderate (r_s=

169 0.49; P<0.001; Figure 1C) and weak (r_s= 0.27; P<0.001; Figure 1D) correlations were found between traditional peak

170 torque and power output H:Qnon-fatigued, and traditional peak torque and power output H:Qfatigued, respectively.

171 Insert Figure 1 here

172 When power output H:Qfatigued was stratified based on athletes traditional peak torque H:Q quartiles (Figure 2),

173 those with lower peak torque H:Q (i.e. quartile 1) showed lower levels of power output H:Qfatigued when compared to

174 quartile 3 and 4 (P= .047 and .025, respectively), while further differences were not found among other quartiles (P=0.969

175 to 0.997).

176 Insert Figure 2 here

177 **Discussion**

178 The main purpose of the present study was to examine H:Q derived from peak torque, and power output data

179 under non-fatigued and fatigued states, and to test the relationship between these measurements. The present findings

180 showed that, despite the high agreement between them, H:Q derived from peak torque and power output displayed

181 significant bias and were not strongly associated. Furthermore, while players with the lowest peak torque H:Q also

182 presented the lowest fatigued power output H:Q, this pattern was not found in players with higher H:Q scores.

183   Previous studies comparing maximal isometric voluntary contraction and rate of torque development (RDT) for
184   calculation of H:Q demonstrated differences in muscle balance imbalance outcomes between ways to calculate H:Q (Zebis
185   et al., 2011; Jordan et al., 2015). Moreover, the disagreement between H:Q calculated with peak torque and alternative
186   methods has been reported to be greater with fatigue in professional soccer players (Grazioli et al., 2019) likely reflecting
187   neural and contractile adjustments to fatigue. For example, Buckthorpe et al. (2014) found faster and more pronounced
188   decline in explosive force than maximal isometric voluntary contraction, which was explained by neural and contractile
189   fatigue mechanisms. Explosive strength is highly dependent on the rate of rise in contractile force at the onset of muscle
190   contraction (Greco et al., 2013), which is likely to be influenced by fibre-type composition (Aagaard et al., 2002). Type
191   II skeletal muscle fibers have a substantially higher RTD (Buckthorpe et al., 2014), and contribute to higher power output
192   (Faulkner et al., 1986). However, type II fibers have lower resistance to fatigue resistance, thus one could expect greater
193   influence of fatigue on explosive compared to maximal force production (Hamada et al., 2003; Buckthorpe et al., 2014).
194   Accordingly, we observed a weak-to-moderate correlation between H:Q derived from traditional peak torque and power
195   output, indicating that maximal force and muscle power production are distinct entities. Furthermore, the dissociation
196   between peak torque and power output was more evident with fatigue in players with higher traditional peak torque H:Q.
197   Given these differences, we speculate that power output H:Q$_{fatigued}$ may be a more ecological measurement as it combines
198   both power-related soccer demands and fatigue in a single test that can be widely used in the athletic population.

199   The dissociation between power output vs. traditional peak torque H:Q becomes even more evident when
200   analyzed beyond correlation results. Quartiles analysis indicated that it is not possible to differentiate the power profiles'
201   in higher quartile players based on their peak torque performance (i.e. athletes with higher traditional peak torque H:Q
202   are not necessarily those displaying the greater power output H:Q$_{fatigued}$ ratio). This result reinforces the differences
203   between maximal strength and power output in non-fatigued and fatigued conditions, respectively. For instance,
204   traditional peak torque H:Q is frequently used by teams to assess the potential power of stabilizing the knee and risk of
205   hamstring strain (McCall et al., 2015). However, based on our results, a player with appropriate traditional peak torque
206   H:Q might well be picked to play, irrespective if his or her H:Q were at low levels if assessed based on fatigued power
207   output tests;

208   The present work analysed a large number of high-level professional soccer players, which strength of this study.
209   Additionally, compared to other rapid force assessment methods (e.g., RTD), which require time-consuming data
210   extraction and analysis (Zebis et al., 2011; Maffiulletti et al., 2016), isokinetic peak power measurement is easily available
211   for medical and strength & conditioning staff, and can be effortlessly retrieved from routine isokinetic tests. However,
212   some limitations are worth noting. Firstly, although all participants were familiar with the assessment protocol, the
213   professional players had limited time for laboratory testing and a test-retest reliability assessment could not be performed.
214   Moreover, the transversal design of this study does not allow us to infer the predictive value of power output H:Q ratios
215   regarding injury risk and whether it could inform decisions about return-to-play. Nevertheless, the current findings
216   provide initial evidence to support further investigation of power output H:Q as an alternative method to traditional muscle
217   imbalance assessment.

218   In conclusion, power output H:Q seems to identify a different muscle balance / imbalance profile compared to
219   traditional peak torque H:Q, especially when fatigue is present. Particularly, in athletes with high peak torque H:Q values,
220   muscle balance calculated based on peak torque and power output were weekly correlated and may not represent the same
221   neuromuscular phenomenon. These findings may provide practitioners with new and more specific information to
222   improve routine screening based on physical demands of soccer. Nevertheless, future prospective cohort studies are

needed to investigate whether power-based H:Q could work as an injury prediction variable and serve as a more efficient

screening strategy to inform return-to-play decisions.

References

1. Aagaard P, Simonsen EB, Andersen JL, Magnusson P, Dyhre-Poulsen P. Increased rate of force development and neural drive of human skeletal muscle following resistance training. J Appl Physiol (1985). 2002;93(4):1318-1326. doi:10.1152/japplphysiol.00283.2002

2. Barnes C, Archer DT, Hogg B, Bush M, Bradley PS. The evolution of physical and technical performance parameters in the English Premier League. Int J Sports Med. 2014 Dec;35(13):1095-100. doi: 10.1055/s-0034-1375695. Epub 2014 Jul 10. PubMed PMID: 25009969.

3. Buckthorpe M, Pain MT, Folland JP. Central fatigue contributes to the greater reductions in explosive than maximal strength with high-intensity fatigue. Exp Physiol. 2014 Jul;99(7):964-73. doi: 10.1113/expphysiol.2013.075614. Epub 2014 Apr 11. PubMed PMID: 24728678.

4. Chumanov ES, Heiderscheit BC, Thelen DG. Hamstring musculotendon dynamics during stance and swing phases of high-speed running. Med Sci Sports Exerc. 2011 Mar;43(3):525-32. doi: 10.1249/MSS.0b013e3181f23fe8. PMID: 20689454; PMCID: PMC3057086.

5. Dauty M, Menu P, Fouasson-Chailloux A. Cutoffs of isokinetic strength ratio and hamstring strain prediction in professional soccer players. Scand J Med Sci Sports. 2018 Jan;28(1):276-281. doi: 10.1111/sms.12890. Epub 2017 Apr 20. PubMed PMID: 28378465.

6. Ekstrand J, Hägglund M, Waldén M. Epidemiology of muscle injuries in professional football (soccer). Am J Sports Med. 2011 Jun;39(6):1226-32. doi: 10.1177/0363546510395879. Epub 2011 Feb 18. PubMed PMID: 21335353.

7. Ekstrand, J. Keeping your top players on the pitch: The key to football medicine at a professional level. Br J Sports Med 47: 723–724, 2013.

8. Erickson BJ, Harris JD, Cvetanovich GL, et al. Performance and Return to Sport After Anterior Cruciate Ligament Reconstruction in Male Major League Soccer Players. Orthop J Sports Med. 2013;1(2):2325967113497189. Published 2013 Jul 11. doi:10.1177/2325967113497189.

9. Faulkner JA, Claflin DR, McCully KK. Power output of fast and slow fibers from human skeletal muscles. In: Jones NL, McCartney N, McComas AJ, editors. Human Muscle Power. Champaign, IL: Human Kinetics Publishers, Inc.; p 81-94, 1986.

10. Grazioli R, Lopez P, Andersen LL, Machado CLF, Pinto MD, Cadore EL, Pinto RS. Hamstring rate of torque development is more affected than maximal voluntary contraction after a professional soccer match. Eur J Sport Sci. 2019 Nov;19(10):1336-1341. doi: 10.1080/17461391.2019.1620863. Epub 2019 Jun 1. PubMed PMID: 31099729.

11. Greco CC, da Silva WL, Camarda SR, Denadai BS. Fatigue and rapid hamstring/quadriceps force capacity in professional soccer players. Clin Physiol Funct Imaging. 2013;33(1):18-23. doi:10.1111/j.1475-097X.2012.01160.x

12. Green B, Bourne MN, Pizzari T. Isokinetic strength assessment offers limited predictive validity for detecting risk of future hamstring strain in sport: a systematic review and meta-analysis. Br J Sports Med. 2018 Mar;52(5):329-336. doi: 10.1136/bjsports-2017-098101. Epub 2017 Nov 29. Review. PubMed PMID: 29187349.

13. Hamada T, Sale DG, MacDougall JD, Tarnopolsky MA. Interaction of fibre type, potentiation and fatigue in human knee extensor muscles. Acta Physiol Scand. 2003;178(2):165-173. doi:10.1046/j.1365-201X.2003.01121.x

14. Iossifidou, A., Baltzopoulos, V. Peak power assessment in isokinetic dynamometry. Eur J Appl Physiol 82, 158–160 (2000). https://doi.org/10.1007/s004210050667.

15. Johnston JT, Mandelbaum BR, Schub D, Rodeo SA, Matava MJ, Silvers-Granelli HJ, Cole BJ, ElAttrache NS, McAdams TR, Brophy RH. Video Analysis of Anterior Cruciate Ligament Tears in Professional American Football Athletes. Am J Sports Med. 2018 Mar;46(4):862-868. doi: 10.1177/0363546518756328. Epub 2018 Feb 21. PubMed PMID: 29466019.

16. Jordan MJ, Aagaard P, Herzog W. Rapid hamstrings/quadriceps strength in ACL-reconstructed elite Alpine ski racers. Med Sci Sports Exerc. 2015 Jan;47(1):109-19. doi: 10.1249/MSS.0000000000000375. PubMed PMID: 24824771.

17. Lord C, Ma'ayah F, Blazevich AJ. Change in knee flexor torque after fatiguing exercise identifies previous hamstring injury in football players. Scand J Med Sci Sports. 2018 Mar;28(3):1235-1243. doi: 10.1111/sms.13007. Epub 2018 Jan 8. PubMed PMID: 29117428.

18. Maestroni L. There is something about Power-a gap in Rehabilitation and injury reduction strategies? Scand J Med Sci Sports. 2018 Aug;28(8):1850-1851. doi: 10.1111/sms.13202. PubMed PMID: 29999225.

19. Maffiuletti NA, Aagaard P, Blazevich AJ, Folland J, Tillin N, Duchateau J. Rate of force development: physiological and methodological considerations. Eur J Appl Physiol. 2016 Jun;116(6):1091-116. doi: 10.1007/s00421-016-3346-6. Epub 2016 Mar 3. PMID: 26941023; PMCID: PMC4875063.

20. McCall A, Carling C, Nedelec M, Davison M, Le Gall F, Berthoin S, Dupont G. Risk factors, testing and preventative strategies for non-contact injuries in professional football: current perceptions and practices of 44 teams from various premier leagues. Br J Sports Med. 2014 Sep;48(18):1352-7. doi: 10.1136/bjsports-2014-093439. Epub 2014 May 16. PubMed PMID: 24837243.

21. McCall A, Davison M, Andersen TE, Beasley I, Bizzini M, Dupont G, Duffield R, Carling C, Dvorak J. Injury prevention strategies at the fifa 2014 world cup: Perceptions and practices of the physicians from the 32 participating national teams. Br J Sports Med 49: 603-608, 2015.

22. Minozzo F, Lopez P, Machado CLF, Wilhelm EN, Grazioli R, Pinto RS. Alternative assessment of knee joint muscle balance of soccer players through total work-based hamstring: quadriceps ratios. Eur J Sport Sci. 2018 Nov;18(10):1398-1404. doi: 10.1080/17461391.2018.1495271. Epub 2018 Jul 14. PubMed PMID: 30009683.

23. Oakley AJ, Jennings J, Bishop CJ. Holistic hamstring health: not just the Nordic hamstring exercise. Br J Sports Med. 2018 Jul;52(13):816-817. doi: 10.1136/bjsports-2016-097137. Epub 2017 May 5. PubMed PMID: 28476902.

24. Pinto, Matheus & Blazevich, Anthony & Andersen, Lars & Mil-Homens, Pedro & Pinto, Ronei. (2017). Hamstring-to-quadriceps fatigue ratio offers new and different muscle function information than the conventional non-fatigued ratio. Scandinavian journal of medicine & science in sports. 28. 10.1111/sms.12891.

25. Rekik RN, Tabben M, Eirale C, Landreau P, Bouras R, Wilson MG, Gillogly S, Bahr R, Chamari K. ACL injury incidence, severity and patterns in professional male soccer players in a Middle Eastern league. BMJ Open Sport Exerc Med. 2018 Oct 23;4(1): e000461. doi: 10.1136/bmjsem-2018-000461. PMID: 30498577; PMCID: PMC6241976.

26. Ruas, C.V., Pinto, R.S., Haff, G.G. et al. Alternative Methods of Determining Hamstrings-to-Quadriceps Ratios: a Comprehensive Review. Sports Med - Open 5, 11 (2019). https://doi.org/10.1186/s40798-019-0185-0

27. Sahaly R, Vandewalle H, Driss T, Monod H. Maximal voluntary force and rate of force development in humans-- importance of instruction. Eur J Appl Physiol. 2001 Aug;85(3-4):345-50. PubMed PMID: 11560090.

28. Iossidou AN, Baltzopoulos V (1996) Actual angular velocity in eccentric isokinetic dynamometry. Isokin Exerc Sci 6: 65±70

29. van Dyk N, Bahr R, Whiteley R, Tol JL, Kumar BD, Hamilton B, Farooq A, Witvrouw E. Hamstring and Quadriceps Isokinetic Strength Deficits Are Weak Risk Factors for Hamstring Strain Injuries: A 4-Year Cohort Study. Am J

305   Sports Med. 2016 Jul;44(7):1789-95. doi: 10.1177/0363546516632526. Epub 2016 Mar 21. PubMed PMID:
306   27002102.
307 30. Zambaldi M, Beasley I, Rushton A. Return to play criteria after hamstring muscle injury in professional football: a
308   Delphi consensus study. Br J Sports Med. 2017 Aug;51(16):1221-1226. doi: 10.1136/bjsports-2016-097131. Epub
309   2017 Feb 28. PubMed PMID: 28246078.
310 31. Zebis MK, Andersen LL, Ellingsgaard H, Aagaard P. Rapid hamstring/quadriceps force capacity in male vs. female
311   elite soccer players. J Strength Cond Res. 2011 Jul;25(7):1989-93. doi: 10.1519/JSC.0b013e3181e501a6. PubMed
312   PMID: 21701286.

313

314　**Table 1. Comparisons between peak torque at $60°·s^{-1}$ and peak power at $300°·s^{-1}$ values in non- and fatigued**

315　**isokinetic conditions.**

Variable	Non-fatigued Mean ± SD [95% CI]	Fatigued Mean ± SD [95% CI]	Mean difference	95% CI	P-value
Knee extension					
Peak torque at $60°·s^{-1}$, N·m[†]	240.8 ± 41.0 [234.4 to 247.2]	-	-	-	-
Power at $300°·s^{-1}$, W	371.7 ± 59.5 [362.4 to 381.0]	220.4 ± 34.9 [215.0 to 225.9]	-151.3	-158.6 to -144.0	<.001
Knee flexion					
Peak torque at $60°·s^{-1}$, N·m [†]	146.7 ± 29.1 [142.1 to 151.2]	-	-	-	-
Power at $300°·s^{-1}$, W	253.4 ± 51.6 [245.4 to 261.5]	122.8 ± 33.0 [117.7 to 128.0]	-130.6	-136.8 to -124.4	<.001
H:Q					
Peak torque at $60°·s^{-1}$[†]	0.62 ± 0.12 [0.60 to 0.64]	-	-	-	-
Power at $300°·s^{-1}$	0.68 ± 0.11 [0.67 to 0.70]	0.56 ± 0.13 [0.54 to 0.58]	-0.12	-0.15 to -0.11	<.001

316　*SD = standard deviation; CI = confidence interval; [†], Test not performed under fatigue; H:Q, hamstring-to-quadriceps*

317　*ratio.*

318

319   ***Figure 1.*** *Bland-Altman plots of traditional peak torque, power output H:Q$_{non\text{-}fatigued}$ (A) and power output H:Q$_{fatigued}$*
320   *values (B), and correlation between individual scores in traditional peak torque, power output H:Q$_{non\text{-}fatigued}$ (C) and*
321   *power output H:Q$_{fatigued}$ values (D).*
322
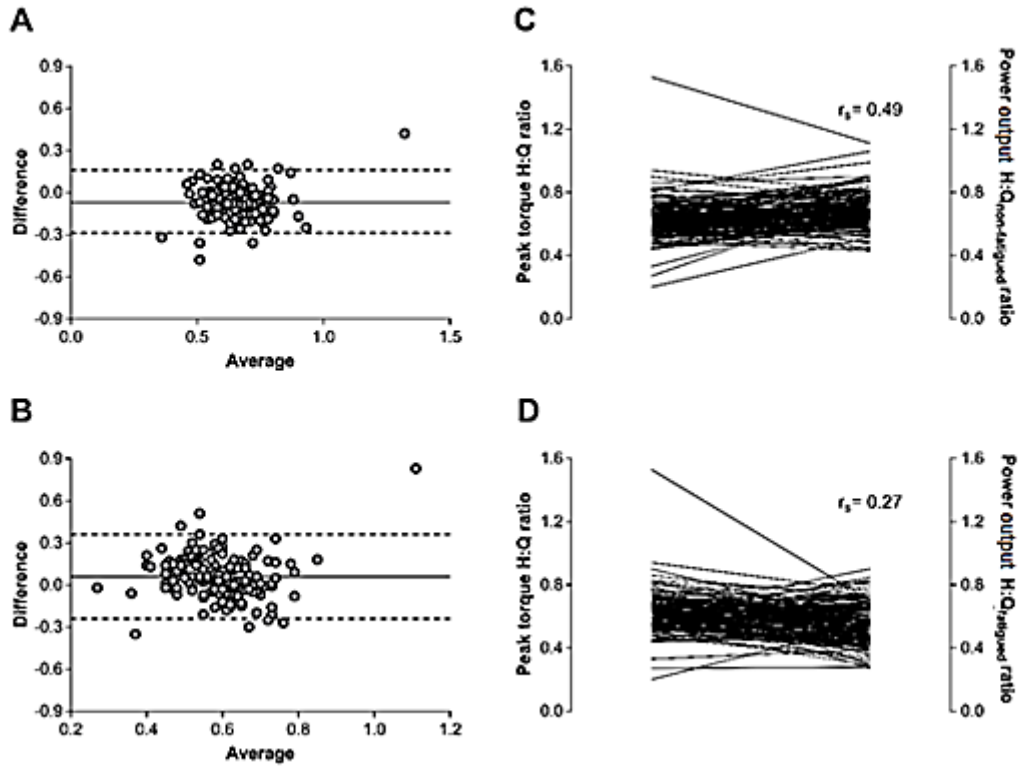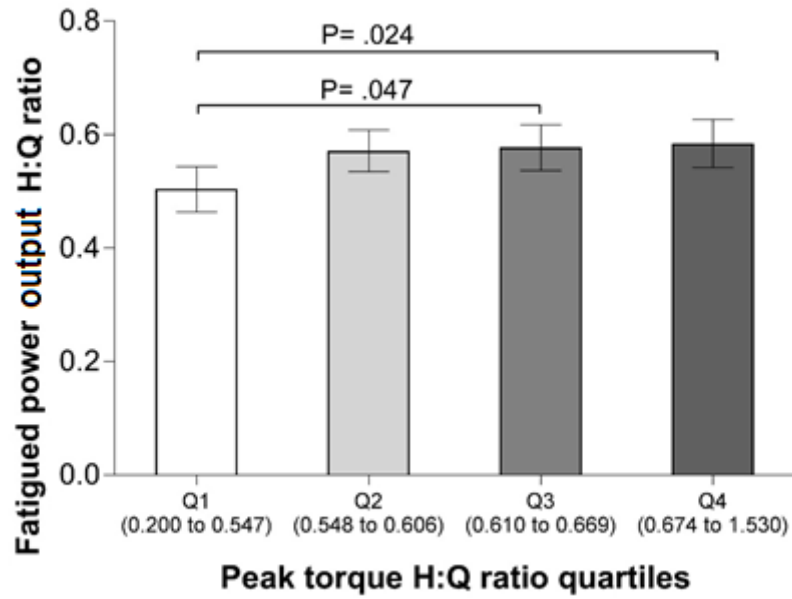
Figure 2. Absolute values and 95% confidence intervals of fatigued power output H:Q values according to traditional peak torque H:Q quartiles. Quartile 1 (Q1) lowest traditional peak torque H:Q values to quartile 4 (Q4) highest traditional peak torque H:Q values. Traditional peak torque H:Q cut-points were 0.548 for Q2, 0.610 for Q3, and 0.674 for Q4. The P-value is for comparisons between quartiles