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

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Running title: The new power output H:$Q_{fatigued}$ ratio

## Abstract

**Background:** Muscle strength imbalance assessment (e.g. hamstring-to-quadriceps ratio, H:Q) using traditional peak torque isokinetic measurements has been shown to be a weak risk factor predictor of future lower-limb injuries (e.g. hamstring strain and anterior cruciate ligament tear). In soccer, power-related tasks are commonplace and injuries are most likely to occur during fatigued high-velocity actions. Thus, it is reasonable to that calculating H:Q using power output may serve as an alternative to traditional peak torque-based H:Q. **Aims:** We aimed to investigate the relationship of isokinetic H:Q calculated from traditional peak torque and power output during non-fatigue and fatigue conditions. **Methods:** Seventy-nine professional soccer players (25.6 ± 4.9 years old; 78.7 ± 8.1 kg; 179.4 ± 6.7 cm) performed concentric knee extension-flexion contractions at $60^{o}\cdot s^{-1}$ (5 repetitions) and $300^{o}\cdot s^{-1}$ (30 repetitions, fatigue trial). Traditional peak torque H:Q was calculated using the highest torque obtained during five repetitions at $60^{o}\cdot s^{-1}$. Power output $H{:}Q_{non\text{-}fatigued}$ was calculated using the average from the 2nd, 3rd and 4th repetitions, and power output $H{:}Q_{fatigued}$ 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 moderate ($r_s$= 0.49) correlations were found between traditional peak torque and power output $H{:}Q_{fatigued}$, and traditional peak torque and power output $H{:}Q_{non\text{-}fatigued}$, respectively. **Conclusion:** The present data suggested that power H:Q differ from traditional H:Q, particularly during fatigue in professional soccer players, which warrants further investigation on the potential use of power output H:Q ratios for injury prediction.

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

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

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

## Introduction

Power-related tasks such as jumping, and sprinting are essential for soccer performance (Maestroni, 2018). Over the past fifteen years, high-intensity running has increased about 50% in professional soccer matches with elite players increasing the number and distance of sprints by ~35 and 85%, respectively (Barnes et al., 2014). Unfortunately, the incidence of lower-limb injuries such as hamstring strain and knee ligament tears has also been reported (Ekstrand et al., 2011; Erickson et al., 2013). For example, an increase of ~4% and ~6% per year has been reported for hamstring strain and knee ligament tears, respectively (Ekstrand et al., 2011; Rekik et al., 2018), which highlights the need for a more comprehensive injury prevention program and screening strategies (Oakley et al., 2018; Zambaldi et al., 2017).

Several approaches have been employed to stratify injury risk and help decision-making about return-to-play in soccer, with isokinetic testing being a common choice (McCall et al., 2014). However, studies by van Dyk et al. (2016), Green et al. (2018) and Dauty et al. (2018) have recently highlighted the low predictive potential value for hamstring and knee ligament tears injuries of traditional isokinetic parameters in soccer players (e.g. peak torque-based hamstring to quadriceps ratio – H:Q). Moreover, since hamstring strain and knee injuries are most likely to occur during high-velocity tasks (Chumanov et al., 2011; Johnston et al., 2018) or in conditions of neuromuscular fatigue (Ekstrand et al., 2011), the traditional peak torque parameters taken from isokinetic tests performed at relatively slow angular velocity (e.g., $60°\cdot s^{-1}$) may not reflect the demands associated with elite soccer performance. As such, new and more ecological approaches are needed to improve injury prediction, prevention, and inform return-to-play decision for professional athletes.

Quantification of H:Q based on alternative isokinetic parameters, such as the total work produced in concentric and eccentric knee actions (Minozzo et al., 2018), and during fatigue conditions (Pinto et al., 2017; Lord, Ma'ayah & Blazevich, 2018) have been shown to differ from peak torque-based H:Q. Accordingly, assessment of isokinetic power output may be an alternative to peak torque for H:Q calculation, as it may reflect more closely the demands of powerful tasks in elite sports (Maestroni, 2018). In addition, the ability to generate force at higher angular speed seems to be more affected by fatigue than peak torque (Buckthorpe et al., 2014; Grazioli et al., 2019), which could be associated to increased risk of injury during power-related tasks. Hence, peak power output derived from isokinetic dynamometry tests (i.e., product of moment and angular velocity (Iossifidou and Baltzopoulos, 2000)) may be an alternative to traditional H:Q ratios to inform coaches and players about injury risk. However, the relationship between power output and peak torque values on H:Q ratio calculations, as well as the influence of fatigue on such ratios, has been overlooked.

Thus, the purpose of the present study was to investigate the relationship of isokinetic H:Q calculated from traditional peak torque and power output during non-fatigue and fatigue conditions. Our hypothesis is that H:Q scores calculated using power output represent a distinct phenomena compared to traditional peak torque H:Q calculations and, hence, will result in distinct and unrelated scores in each athlete.

## Materials and methods

### *Participants*

Seventy-nine male professional soccer players (25.6 ± 4.9 years old; 78.7 ± 8.1 kg; 179.4 ± 6.7 cm) from three soccer teams playing at national and international levels volunteered for this study. All players were asymptomatic and free from injuries and provided written consent to this study. Tests were performed in both lower limbs during pre-season as part of the players' screening procedure, and data was then retrieved from laboratory database. The regional research ethical committee approved this study (approval number: 2.903.811).

*Isokinetic Protocols*

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

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

*Isokinetic protocol analysis*

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

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

*Statistical analysis*

Data normality was assessed using the Shapiro-Wilk test, and descriptive values are shown as mean ± standard deviation (SD) and 95% confidence intervals (95% CI). Independent T-tests were used to compare right and left lower limbs isokinetic values. Since no difference in performance parameters was observed between right and left limb data, both limbs of participants were considered for analysis a single dataset. Paired sample T-test was performed to examine changes in isokinetic performance with the fatigue protocol. Bland-Altman analysis and limits of agreement (±1.96 SDs or the 95% CI) were used to illustrate agreement between measurements and identify bias. A linear regression was used to test for proportional bias. Furthermore, the Spearman's rank-order correlation was employed to assess the relationship between H:Q within the cohort. Finally, traditional peak torque H:Q values were used as an ordinal variable to define quartiles, and one-way analysis of variance (ANOVA) with Tukey's *post hoc* were used to compare the power output H:Qfatigued values among quartiles. The level of significance (α) was set at 0.05 and all statistical procedures were performed using the Statistical Package for Social Science (SPSS) version 20.0 (IBM SPSS Inc., IL, USA).

## Results

### *Isokinetic tests performance*

No differences were found at baseline between limbs for knee extension (right = 240.6 ± 39.6; left = 240.9 ± 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, power output did not differ between the right and left limbs during knee extension (right = 354.2 ± 58.9; left = 355.6 ± 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 between limbs power output during fatigue was observed for knee extension (right = 220.6 ± 35.5; left = 220.3 ± 34.5 W, P = 0.811) and flexion (right = 124.5 ± 35.6; left = 121.1 ± 30.4 W, P = 0.402). Hence, further analyses were conducted using the whole sample (n = 158 lower limbs). Table 1 describes the comparisons made between different conditions. By the end of the fatigue protocol, knee extension power output was reduced by 151.3 W (95% CI: -158.6 to -144.0; P < 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 reduced from an average of 0.68 to 0.56 (95% CI: -0.15 to -0.11; P < 0.001) with fatigue.

Insert Table 1 here

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

Bland-Altman plots showed high agreement between traditional peak torque and both power output $H:Q_{non\text{-}fatigued}$ and power output $H:Q_{fatigued}$, while a significant proportional bias (t= 2.31, P= 0.022; Figure 1 panel A) and a non-significant systematic trend (t=0.04, P=0.969; Figure 1 panel B) were found, respectively. Furthermore, moderate ($r_s$= 0.49; P<0.001; Figure 1C) and weak ($r_s$= 0.27; P<0.001; Figure 1D) correlations were found between traditional peak torque and power output $H:Q_{non\text{-}fatigued}$, and traditional peak torque and power output $H:Q_{fatigued}$, respectively.

Insert Figure 1 here

When power output $H:Q_{fatigued}$ was stratified based on athletes traditional peak torque H:Q quartiles (Figure 2), those with lower peak torque H:Q (i.e. quartile 1) showed lower levels of power output $H:Q_{fatigued}$ when compared to quartile 3 and 4 (P= .047 and .025, respectively), while further differences were not found among other quartiles (P=0.969 to 0.997).

Insert Figure 2 here

## Discussion

The main purpose of the present study was to examine H:Q derived from peak torque, and power output data under non-fatigued and fatigued states, and to test the relationship between these measurements. The present findings showed that, despite the high agreement between them, H:Q derived from peak torque and power output displayed significant bias and were not strongly associated. Furthermore, while players with the lowest peak torque H:Q also presented the lowest fatigued power output H:Q, this pattern was not found in players with higher H:Q scores.

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

The dissociation between power output vs. traditional peak torque H:Q becomes even more evident when analyzed beyond correlation results. Quartiles analysis indicated that it is not possible to differentiate the power profiles' in higher quartile players based on their peak torque performance (i.e. athletes with higher traditional peak torque H:Q are not necessarily those displaying the greater power output $H:Q_{fatigued}$ ratio). This result reinforces the differences between maximal strength and power output in non-fatigued and fatigued conditions, respectively. For instance, traditional peak torque H:Q is frequently used by teams to assess the potential power of stabilizing the knee and risk of hamstring strain (McCall et al., 2015). However, based on our results, a player with appropriate traditional peak torque 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 output tests;

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

In conclusion, power output H:Q seems to identify a different muscle balance / imbalance profile compared to traditional peak torque H:Q, especially when fatigue is present. Particularly, in athletes with high peak torque H:Q values, muscle balance calculated based on peak torque and power output were weekly correlated and may not represent the same neuromuscular phenomenon. These findings may provide practitioners with new and more specific information to 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.

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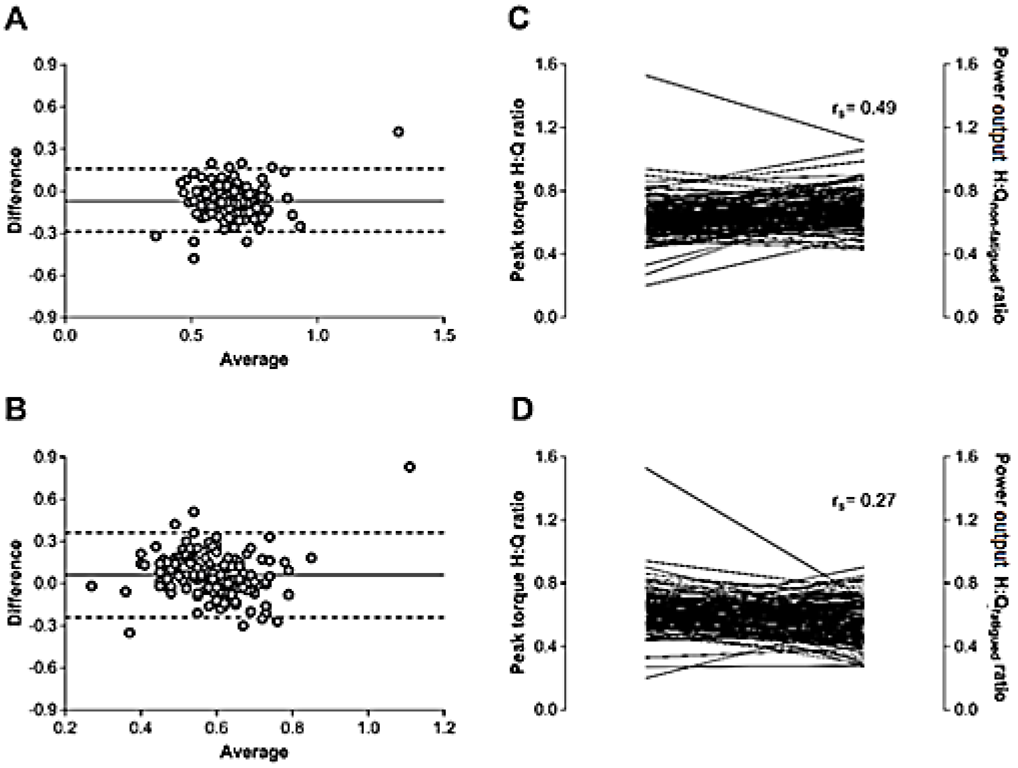
**Table 1. Comparisons between peak torque at 60°·s$^{-1}$ and peak power at 300°·s$^{-1}$ values in non- and fatigued isokinetic conditions.**

| 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<br>[234.4 to 247.2] | - | - | - | - |
| Power at 300°·s$^{-1}$, W | 371.7 ± 59.5<br>[362.4 to 381.0] | 220.4 ± 34.9<br>[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<br>[142.1 to 151.2] | - | - | - | - |
| Power at 300°·s$^{-1}$, W | 253.4 ± 51.6<br>[245.4 to 261.5] | 122.8 ± 33.0<br>[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<br>[0.60 to 0.64] | - | - | - | - |
| Power at 300°·s$^{-1}$ | 0.68 ± 0.11<br>[0.67 to 0.70] | 0.56 ± 0.13<br>[0.54 to 0.58] | -0.12 | -0.15 to -0.11 | <.001 |

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

***Figure 1.*** *Bland-Altman plots of traditional peak torque, power output H:Q*$_{non\text{-}fatigued}$ *(A) and power output H:Q*$_{fatigued}$ *values (B), and correlation between individual scores in traditional peak torque, power output H:Q*$_{non\text{-}fatigued}$ *(C) and power output H:Q*$_{fatigued}$ *values (D).*



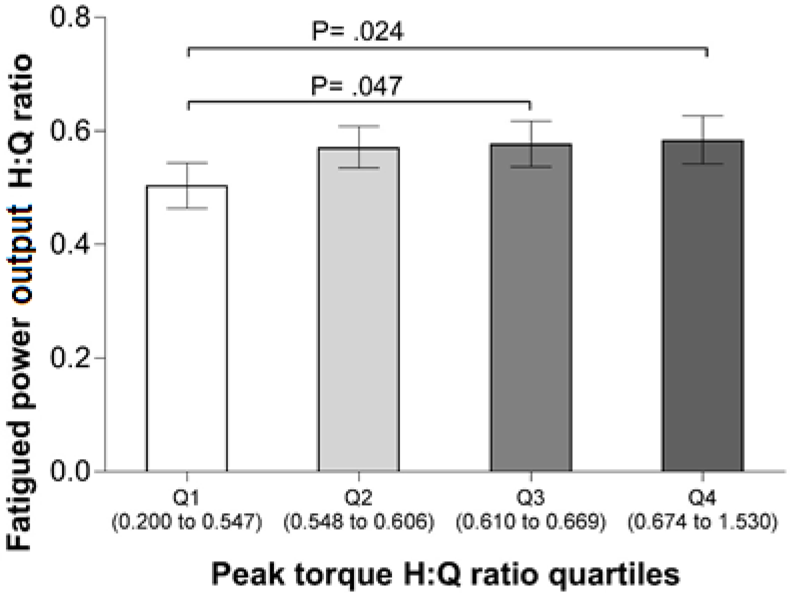


***Figure 2.*** *Absolute values and 95% confidence intervals of fatigued power output H:Q values according to traditional peak torque H:Q quartiles. Quartile 1 (Q1) lowest traditional peak torque H:Q values to quartile 4 (Q4) highest traditional peak torque H:Q values. Traditional peak torque H:Q cut-points were 0.548 for Q2, 0.610 for Q3, and 0.674 for Q4. The P-value is for comparisons between quartiles*