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ORIGINAL ARTICLE

Neuromuscular fatigue effects on Hamstring to Quadriceps Ratio in young female players

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Abstract
Introduction: Two of the main modifiable risk factors for suffering an injury in the anterior cruciate ligament are known to be the Hamstring-to-Quadriceps (*H*/*Q*) Ratio and neuromuscular fatigue.

The main purpose of this research was to study the effect of neuromuscular fatigue on the *H*/*Q* Ratio and the maximum isometric strength of the quadriceps and hamstrings in teenage female basketball and handball players.

Material and methods: This is an experimental, pre-post intervention study with a sample of 19 female basketball players and 11 female handball players (17.02 ± 1.19 yo, 177.8 ± 7.2 cm and 68.6 ± 9.3 kg). To assess muscle strength, a maximum isometric strength test was performed in a 90° hip and 60° knee position. The *H*/*Q* Ratio was then calculated. The 30–15 Intermittent Fatigue Test (30–15 IFT) was used to induce fatigue, measured using the Rating of Perceived Exertion (RPE) scale. A descriptive analysis and a Student's *t*-test were performed to study the differences in the *H*/*Q* Ratio, muscle strength and pre-post intervention fatigue.

Results: Although the *H*/*Q* Ratio decreased after the 30–15 IFT, the differences were not statistically significant. Regarding strength values, the right and left quadriceps presented strength reductions of 4.52% and 5.55%, respectively. The reduction in strength was statistically significant ($p \leq 0.05$), especially in the right hamstring (7.3%) and in the left hamstring (7.5%).

The study conclusions suggest that leg muscular strength decreases after a fatigue test and that there is a tendency for the *H*/*Q* Ratio to decrease also.

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Introduction

Basketball and handball are two of the most widely played team sports in Europe.[1] They are also two of the team sports with the highest incidence of injury, particularly handball. Studies record seven to 10 injuries per 1000 hours of sports performance in women's basketball[2–5] and 40.7 injuries per 1000 hours of sports performance in women's handball.[1,6] Most injuries occur in the legs, at 58–74% in basketball and 54–59% in handball.[3,6] Women players are two to 10 times more likely than men players to sustain certain injuries, such as anterior cruciate ligament (ACL) injuries,[7] ankle sprains[2–4] and patellofemoral pain.[3,4] ACL injuries have an incidence of 0.28 per 1000 hours of play in women's basketball[5] and 0.97 per 1000 hours in women's handball.[8]

Although there are numerous factors in ACL injury risk, abnormalities in movement patterns, such as dynamic knee valgus, during high-impact activities such as changes of direction, landing and decelerations, are modifiable.[9] These changes in appropriate movement patterns are often associated with neuromuscular control deficits.[10] The neuromuscular deficits which may contribute to poor biomechanical control and consequently lead to ACL injuries include: (a) quadriceps dominance[9] or weak hamstrings[7,11,12]; (b) highly unbalanced Hamstring-to-Quadriceps Ratio (*H*/*Q* Ratio)[13]; (c) muscle strength deficits in the leg[7]; (d) neuromuscular fatigue[14,15] and (e) neuromuscular asymmetries between the legs.[16]

The studies calculate the *H*/*Q* Ratio by means of isokinetic strength tests, and find that normal values in athletes range from 0.5 to 0.8 depending on the angular speed of test performance.[17–20] However, strength evaluation using an isokinetic dynamometer is often inaccessible due to its high cost. This has prompted many authors to turn to a manual dynamometer as a valid and reliable solution with moderate-high correlation with quadriceps and hamstring isokinetic strength tests.[13,19,20] Although there are some studies which report ratios of 0.48 in the seated position with the knee at 120°,[19] in 2018, Peek et al. concluded that there is a lack of studies establishing normal *H*/*Q* Ratio values measured in isometric exercise.[20]

In terms of strength, quadriceps strength increases in boys during puberty by 148% and hamstring strength by 179%, while in girls it increases by 44% and 27%, respectively. This means the *H*/*Q* Ratio diminishes in girls and their risk of sustaining an ACL injury increases.[21]

With regard to fatigue, epidemiological studies point to a high incidence in the last few minutes of each half of games,[22] which they associate with this factor.[15] Although there are few studies, some researchers show that women players present lower muscle strength values[23,24] and also lower *H*/*Q* Ratios[15,24] in conditions of fatigue. Pinto et al. performed a fatigue test in 2017 and found that strength values and the *H*/*Q* Ratio decreased, concluding that the hamstrings become fatigued before the quadriceps and that there is therefore a risk of sustaining an ACL injury.[24]

As already noted, the *H*/*Q* Ratio, muscle strength and neuromuscular fatigue are three very important risk factors for injury[12] and studying them may help to reduce exposure to certain injuries, such as ACL. Given the current state of the literature, there is little evidence about the *H*/*Q* Ratio in teenage female basketball and handball players, since there are no standardised values for it in which strength values are obtained in isometric exercise using a manual dynamometer. There are also few studies which observe how this ratio behaves in conditions of fatigue.

The main objective of this research was to study the impact of neuromuscular fatigue on the *H*/*Q* Ratio in teenage female basketball and handball players. A secondary objective was to investigate how neuromuscular fatigue affects the maximum isometric strength of quadriceps and hamstrings.

Material and methods

Study design

This study used an experimental, prospective pre-post intervention design to compare the *H*/*Q* Ratio and maximum isometric muscle strength before and after an intermittent fatigue test in a group of high-performance female basketball and handball players. The strength test performed by the players was used to obtain the maximum isometric strength values in Newtons (N) and to calculate the *H*/*Q* Ratio. This test was repeated before and after the 30–15 intermittent fatigue test (30–15 IFT) in order to compare the values obtained.

Study sample

The inclusion criteria for this study were being a high-performance female basketball or handball player between the ages of 14 and 18 years. The players had to do between 15 and 20 hours of physical exercise a week, counting training and games.

Players who had an injury (acute or chronic) at the time of the test or who had played a game in the two days prior to the study were excluded.

The above criteria yielded a sample of 30 participants. This size was calculated by accepting an alpha risk of 0.05 and a beta risk of less than 0.2, a two-sided contrast, seeking to detect a difference of 0.3 units or more. A standard deviation of 0.55 and a loss to follow-up rate of 10% was assumed. Nineteen female basketball players from the ''Segle XXI'' team and 11 female handball players from the Joaquim Blume Residence training facility were selected.

Evaluation and testing

The players attended two sessions over a 14-day period, the first one to familiarise themselves with the tests and the second one for data gathering. On data gathering day, they presented in groups of five and started with a warm-up (Appendix 1) followed by a maximum isometric strength test, providing a value for the Rating of Perceived Exertion (RPE) scale. Once the tests had been completed, the 30–15 IFT was carried out and the initial evaluations were repeated.

Figure 1 Maximum isometric strength test: maximum isometric strength test of quadriceps (a) and maximum isometric strength test of hamstrings (b).

Maximum isometric strength test

The maximum strength of the quadriceps and hamstrings was measured isometrically. The ''Mark-10 Series 3 Digital Force Gauge'' handheld dynamometer was used to perform the test. The players were asked to exercise on a quadriceps extension bench where the hip was at 90° of flexion and the knee at 120° (60° from the anatomical extension position). The dynamometer was attached to the pad on the arm of the machine to do the isometrics of the quadriceps and was rotated for the hamstrings (Fig. 1). The players performed three progressive isometric exercises to warm up, aiming for sub-maximum strength. They then performed three repetitions lasting between 5″ and 8″ progressively aiming for the maximum isometric strength of both quadriceps and hamstrings. In quadriceps, the point of contact was 5 cm above the peroneal malleolus and in hamstrings it was above the heel. The players were monitored to make sure they did not compensate by lifting their buttocks and/or moving their trunk forward during the test. Both the starting leg and the muscle group were randomised when they performed the maximum isometric strength test using the ''Oxford Minimization and Randomization'' (OxMaR) digital programme.

The maximum isometric strength (N) variable and the *H/Q* Ratio were recorded with the maximum isometric strength test.

Rating of Perceived Exertion (RPE) scale

Appendix 2 shows the rating of perceived exertion scale given to the players. They had to read and understand the scale and were asked to provide one score before the data gathering commenced and then 30 min after the fatigue test was deemed completed. The RPE value was from 1 to 10.

Intervention

The study intervention was conducted using a 30–15 intermittent fatigue test in which the players had to run for a period of 30 s followed by 15 s of recovery. The test started at a speed of 8 kph in the first 30-s period and in each series, i.e. every 45 s, the speed was increased by 0.5 kph. The test had three zones: A and C, which were the ends, measuring 3 m, and zone B, in the middle, measuring 6 m. The distance between both ends was adapted to basketball (28 m) and speed of performance was set by a whistle (Appendix 3). The players had to complete as many stages as possible. The test ended when they failed to reach one of the three zones for the second time. This test was chosen because of its similarity to the actual game, since both basketball and handball are intermittent sports in which intensity actions are followed by short periods of rest or low intensity.[25–27]

Statistical analysis

The results were analysed using the Statistical Package for the Social Sciences (SPSS) version 18.0 for Windows. The quantitative variables obtained in the study were described by central tendency and dispersion measures, namely the mean and standard deviation.

In all cases, normality was compared using the Shapiro–Wilk test for sample size $n < 50$.

Student's dependent samples t-distribution was used to detect significance in the *H/Q* Ratio, in muscle strength and in the pre-post 30–15 IFT RPE, since the three variables followed a normal distribution.

All the statistical tests were set with a significance level of $\alpha \leq 0.05$.

Ethical considerations

The study was submitted to and accepted by the Blanquerna Faculty of Health Sciences Research Ethics Committee (CER-FCSB) and complied with the principles of the 1975 Helsinki Declaration as revised in 1983.

An information sheet accompanied by an informed consent form was given to the players and their parents and/or legal guardian. Both of them had to read and sign it stating they voluntarily agreed to participate in the study.

Results

Nineteen of the 30 female players studied were basketball players and 11 were handball players. The mean age of the sportswomen was 17.02 ± 1.19 years. In terms of anthropometric data, their mean height was 177.8 ± 7.2 cm and mean body weight was 68.6 ± 9.3 kg. These anthropometric data are shown in Table 1 by sport, age and in general.

The *H/Q* Ratio of the players' right and left legs was calculated before and after the fatigue test. The mean *H/Q* Ratio of the right leg of the players before the 30–15 IFT was 0.52 ± 0.08 and after the 30–15 IFT it was 0.50 ± 0.09. The mean *H/Q* Ratio for the left leg before the 30–15 IFT was 0.52 ± 0.13 and after the 30–15 IFT it was 0.50 ± 0.13.

Table 1 Participants' anthropometric data (*n*: 30).

	Basketball		Handball		
	U-16 ($n=9$)	U-18 ($n=10$)	U-16 ($n=4$)	U-18 ($n=7$)	Total ($n=30$)
Age (years)	15.93 ± 0.61	18.04 ± 0.60	15.71 ± 0.66	17.72 ± 0.57	17.02 ± 1.19
Height (cm)	177.9 ± 7.3	181.5 ± 7.5	175.2 ± 5.8	173.9 ± 5.5	177.8 ± 7.2
Weight (kg)	71.3 ± 10.1	71.4 ± 10.9	63.9 ± 7.6	64.0 ± 3.8	68.6 ± 9.3

Table 2 Right and left leg *H*/*Q* Ratio before and after the 30–15 IFT.

	R ratio ($n=30$)	L ratio ($n=30$)
Pre 30–15 IFT	0.523 ± 0.8	0.512 ± 0.13
Post 30–15 IFT	0.506 ± 0.9	0.508 ± 0.13
p-Value	≤0.30	≤0.35

R = right; L = left.

This difference in values between the *H*/*Q* Ratio was not statistically significant in the right leg ($p \leq 0.3$) or in the left leg ($p \leq 0.35$) (Table 2).

Table 3 shows the pre- and post-fatigue test strength values obtained in the position described above. In all muscle groups there was a significant loss of strength in the RQ $p \leq 0.05$, in the LQ $p \leq 0.01$, in the RH $p < 0.01$ and in the LH $p < 0.01$.

Finally, Table 4 shows the RPE values; the mean before the fatigue test was 2.43 ± 2 and the mean after it was 6.10 ± 1.8 to yield $p < 0.01$.

Discussion

With respect to the study's objectives, in this sample the *H*/*Q* Ratio did not decrease significantly in conditions of fatigue ($p \leq 0.3$ right leg and $p \leq 0.35$ left leg). However, quadriceps and hamstring strength values did decrease significantly in mean values after the fatigue test and more so in hamstrings (−7.40%, $p \leq 0.01$) than in quadriceps (−5.04%, $p \leq 0.01$).

The main purpose of this research was to study the impact of neuromuscular fatigue on the *H*/*Q* Ratio in teenage female basketball and handball players. The results of the study show that the decrease in the *H*/*Q* Ratio was not statistically significant in either the right leg ($p \leq 0.3$) or the left leg ($p \leq 0.35$). Nonetheless, there is a tendency for the *H*/*Q* Ratio to decrease in conditions of fatigue, and while not statistically significant, these results may be clinically significant.[28]

In order to compare the baseline *H*/*Q* ratios with other studies, in 2018, Kabacinski et al. conducted an isokinetic strength test with 14 female basketball players aged 19.8 ± 1.4 years and recorded *H*/*Q* Ratios of 0.48–0.55 at 60°/s and 180°/s, respectively, while in 2001, Rosene et al. recorded *H*/*Q* Ratios of 0.55 (60°/s) with a sample of 10 female basketball players aged 19.3 ± 1.32 years. Similarly, in 2017, Pallicer-Chenoll et al. conducted an isokinetic strength test in female football players aged 22.62 ± 4.69 years, finding *H*/*Q* Ratio values of 0.48, whereas in this study the female players presented a mean *H*/*Q* Ratio of 0.52. The studies that tested the *H*/*Q* Ratio in male players found an *H*/*Q* Ratio in isokinetic tests at between 0.49 (60°/s) and 0.8 (240°/s).[28,29] The studies for both female and male players have established that an *H*/*Q* Ratio below 0.4–0.5 is a risk factor for ACL injuries. This relationship cannot be established in this study, as no long-term follow-up has been conducted, although the players do present a value > 0.5 in the Ratio. Although scientific evidence is meagre, some studies have analysed the behaviour of the *H*/*Q* Ratio in conditions of fatigue. The four studies examining how the *H*/*Q* Ratio behaves in conditions of fatigue were conducted with male athletes, three in football[15,24,29] and one with active young men.[23] Pinto et al. in 2017, and Rahnama et al. in 2003, found differences in the *H*/*Q* Ratio in conditions of fatigue. The first group of researchers tested a maximum of 30 repetitions of knee extension and flexion with an isokinetic machine and observed that the *H*/*Q* Ratio diminished as the repetitions were performed. On the other hand, Rahnama et al. recorded the *H*/*Q* Ratio before and after a fatigue test (''Loughborough Intermittent Shuttle Test'') and also observed lower *H*/*Q* Ratios in fatigue. In 2010, Delextrat et al. conducted a similar study to the previous one in which they found that the *H*/*Q* Ratio decreased after a fatigue test, albeit not significantly. By contrast, in 2018, Behan et al. recorded the explosive *H*/*Q* Ratio with an isokinetic test and found no differences in conditions of fatigue.

In this study, the *H*/*Q* Ratio did not decrease significantly after the fatigue test but did show a tendency to fall. This might be due to the fact that the knee flexors become more

Table 3 Quadriceps and hamstring muscle strength before and after the 30–15 IFT.

	S RQ ($n=30$)	S LQ ($n=30$)	S RH ($n=30$)	S LH ($n=30$)
Pre 30–15 IFT	531 ± 83 N	505 ± 127 N	274 ± 41 N	267 ± 60 N
Post 30–15 IFT	507 ± 91 N	477 ± 121 N	254 ± 49 N	247 ± 62 N
p-Value	≤0.05	≤0.01	<0.01	<0.01

S = strength; RQ = right quadriceps; LQ = left quadriceps; RH = right hamstring; LH = left hamstring.

Table 4 RPE values pre and post 30–15 IFT.

	RPE ($n = 30$)	p-Value
Pre 30–15 IFT	2 ± 2	<0.01
Post 30–15 IFT	6 ± 2	

RPE = Rating of Perceived Exertion.

fatigued than the extensors, and as there is greater loss of strength in the hamstrings the H/Q Ratio value drops, leading to a rise in the difference between these two muscle groups.[23]

Turning to the secondary objective, namely to investigate how neuromuscular fatigue impacts the maximum isometric strength of quadriceps and hamstrings, in this study the muscular strength of quadriceps and hamstrings was found to decrease significantly in conditions of fatigue ($p \leq 0.01$). However, some researchers had already reported loss of strength of the quadriceps and hamstrings in conditions of fatigue.[15,24,29] More specifically, in 2018, Behan et al. conducted a study in which they performed a fatigue test (''Loughborough Intermittent Shuttle Test'') and found a 12% loss of quadriceps strength and a 15% loss of hamstring strength, with the loss of knee flexor strength being greater. These findings are similar to this study's, in which a loss of strength of 5% in quadriceps and 7.4% in hamstrings was recorded. The loss of strength in Behan et al.'s research was greater than in this study. This may be due to the level of training, as Behan et al.'s sample consisted of active participants, whereas this sample comprised high-performance female players. However, both studies recorded a greater loss of strength in the knee flexors than in the extensors.

Several studies have chosen the Rating of Perceived Exertion (RPE) scale to identify neuromuscular fatigue.[30–32] The RPE presents a high correlation with the presence of fatigue biomarkers in blood, such as lactate and ammonia.[30] As the difference in the value obtained on the scale before and after the fatigue test is significant ($p \leq 0.01$), it is concluded that the female players were fatigued after performing the 30–15 IFT.

Concerning the limitations of this study, it should be borne in mind that not all the players did the maximum isometric strength test at the same time and that therefore the recovery time after the fatigue test varied from player to player.

With regard to future studies, it would be useful to compare these results with the male gender to ascertain whether the loss of strength and the variation in the H/Q Ratio after a game are similar to the results found in this study.

This study concludes that the maximum isometric muscle strength of the hamstrings and quadriceps in its sample diminishes after the fatigue test. The hamstrings become slightly more fatigued than the quadriceps and this leads to a tendency for the H/Q Ratio to decrease after the fatigue test as well.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.apunsm.2020.08.001.

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