Review

The influence of fatigue in hamstrings:quadriceps ratio. A systematic review

Juan P. Martín Martínez, Jorge Pérez Gómez, Jorge Carlos Vivas

Universidad de Extremadura.

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Summary

Sport injuries are considered the main cause of cessation of training process, either completely or partially. Among the different types of injuries that may be produced in any sport disciplines, muscular injuries, and more specifically hamstring injuries, are the most common. For that matter the best indicator for evaluating the muscular risk of this kind of injury produced by a muscular imbalance is the hamstrings:quadriceps ratio, of which two types can be distinguished: functional ratio and conventional ratio. The aim of this study was to search in scientific literature how the fatigue presents an influence in the values of both conventional and functional hamstrings:quadriceps ratio as an injury risk indicator. An electronic search of different databases was carried out and a total of thirteen studies publicated until 19th May 2015 were included in this review. The following keywords were employed: "Hamstrings", "quadriceps", "Isokinetic", "Peak torque" and "Fatigue".
Analysed studies showed a significant decrease of both ratios values, but especially functional ratio, after the fatigue protocols application. Besides, a greater decrease of both ratios were noticed when protocols were more specific. This fact means a greatest risk of muscular injury. In addition, the fall in both ratios levels were produced by a decrease in hamstings strength values, in particular during the eccentric phase of movement.
Hence, our results suggest that it would be important to develop an injury prevention strategy focused on delay fatigue, specially in hamstrings, as much as possible and improve hamstrings strength during the eccentric phase of movement.

Key words:
Peak torque. Prevention. Risk. Injury muscular. Strength.

Efecto de la fatiga en el ratio isquiotibiales:cuádriceps. Revisión sistemática

Resumen

Las lesiones deportivas conforman la principal causa por la que el proceso de entrenamiento se ve interrumpido total o parcialmente. Entre los diferentes tipos de lesión que pueden darse en cualquier disciplina deportiva, las lesiones musculares, y más especialmente las que se producen en la musculatura isquiotibial, son las más recurrentes. En este sentido, uno de los indicadores más fiables para cuantificar la descompensación muscular que produce esta lesión es el ratio isquiotibiales: cuádriceps, del cual se diferencian dos tipos: ratio convencional y ratio funcional. El objetivo de esta revisión fue buscar en la literatura científica cómo afecta la fatiga a los valores de ambos ratios que indican el riesgo de sufrir una lesión muscular. Se realizó una búsqueda electrónica en diferentes bases de datos, y un total de trece artículos publicados hasta el 19 de Mayo de 2015 fueron incluidos en el análisis bajo las palabras clave "Hamstrings", "Quadriceps", "Isokinetic", "Peak torque" y "Fatigue".
Los estudios analizados revelaron un importante descenso en los valores de ambos ratios, en especial del funcional, tras la realización de diferentes protocolos de fatiga, sobretodo en aquellos que eran más específicos. Este descenso de los valores del ratio se traduce en un mayor riesgo de sufrir una lesión muscular. Además, el descenso en ambos ratios se producía por una disminución en los valores de fuerza de los isquiotibiales, especialmente durante su fase excéntrica.
Por tanto, los resultados obtenidos sugieren la implantación de estrategias de prevención enfocadas al retraso de la aparición de la fatiga, especialmente en la musculatura isquiotibial, y en el fortalecimiento de la misma durante la fase excéntrica del movimiento.

Palabras clave:
Pico torque. Prevención. Riesgo. Lesión muscular. Fuerza.

Correspondence: Juan Pedro Martín Martínez
E-mail: jpmartinm19@hotmail.com

Introduction

Sporting injuries are the main cause of interruptions to training, and around 30% are related to muscular injuries[1].

Over the years, different strategies have been developed to prevent these types of injuries[2], from theoretical models such as that by Van Machelen *et al*.[3], to more current models[4] that classify the factors that may influence the risk of suffering from a sporting injury into extrinsic and intrinsic factors. Extrinsic factors include the type of competition, the footwear used, the playing surface, or environmental conditions. Intrinsic factors are made up of anatomical, hormonal and neuro-muscular factors. Other authors have also indicated other factors such as deficient flexibility[5], insufficient warm-up[6], the existence of previous injuries[7] and fatigue[8,9] as risk factors in suffering from an injury.

Among the most common with the sporting population, are injuries to the hamstring muscles[10], a muscle-tendon complex formed of different muscles (semitendinosus, semimembrasosus and biceps femoris), that act together[11] and that present a high injury rate in sports that require maximum sprints, blows or ball throws, accelerations and direction changes[12-14]. The most common injury in this muscle group often occurs during the quick extension of the knee, which requires an eccentric action of the hamstrings followed by a deceleration of the leg at the end of the swinging phase in the running technique cycle[15]. Various studies affirm that the risk of injury on a weakened muscle may increase during these eccentric contractions[16,17].

The ratio of the peak torque of the hamstrings and quadriceps has been shown to be one of the most reliable indicators in quantifying the neuro-muscular de-compensation caused by this injury[18]. It has been revealed that a de-compensation in this ratio is correlated to a greater rate of muscular injuries in the lower body[19]. There are two types: The conventional ratio (H:Q) has traditionally been determined by the peak isometric or concentric torque measured using an isokinetic dynamometer (H_{con}:Q_{con})[18]. However, due to the function of these muscles during movement, a new ratio called *"Dynamic Control Ratio"* (DCR) has been proposed by different authors[20-24]. It is calculated as the ratio between the peak torque in eccentric contraction of the hamstring muscles and the peak torque in concentric contraction of the quadriceps (H_{ecc}:Q_{con}). This ratio has also been called "Functional"[21] or "Mixed"[25]. The H:Q ratio values of a healthy knee oscillate between 50% and 80%[26]. It is commonly accepted that an H:Q ratio measured at 60 degrees split by seconds (º/s) (1.05 radians per second raised to minus one [rad*s^{-1}]) of 60% or less, should be treated and rehabilitated to avoid injuries[27]. For its part, the DCR values are generally higher than those of the H:Q Ratio[28], and recent studies suggest that it is more effective when establishing the risk of suffering a hamstring injury[25]. The optimum range of the DCR fluctuates between 0.7 and 1.0[20,29].

Various factors influence the values of both ratios: the angle of the knee in the test, angular speed, the sport chosen, gender[30] and fatigue in the lower limbs, especially at advanced stages of the game[9,31]. Fatigue during play provokes a reduction in the athletes ability to continue to maximum performance[9]. This means that if fatigue is detrimental to the athlete's capacity to produce adequate muscle power, the running cycle mechanism may be altered and, as a result, the risk of injury to the muscles involved increases[32]. Therefore it is necessary to thoroughly understand the effect of fatigue, both on the H:Q ratio and on the DCR, to help establish more effective strategies in preventing and rehabilitating this type of injury[33].

In our bibliographic search we were only able to find two reviews that dealt with some of the influencing factors in the H:Q ratio or DCR[21,29], but none included fatigue. Consequentially, the aim of this review was to gather and exhaustively analyse all the articles that included information about the effects of fatigue on the conventional and functional H:Q ratio.

Material and method

Search strategies in electronic databases and in article selection

To collect the articles we analysed in this review, the scientific information line "Web of Science" was used, from which three important data bases were selected: *Web of Science Core Collection, Medline and Scielo Citation Index*. Two researchers independently examined each of these databases using the following key words: *"Hamstrings", "Quadriceps", "Isokinetic", "Peak torque"* and *"Fatigue"*, and included all studies published until 19th May 2015.

45 articles were identified (Figure 1) and both authors proceeded to read the abstract or the complete article to establish whether or not they complied with the inclusion and exclusion criteria. The inclusion criteria were: (a) Protocols were applied to induce the subjects to fatigue; (b) Adult population (18+ years); (c) Use of Isokinetic Dynamometer to determine the isokinetic strength in the quadriceps and the hamstrings; (d) Article written completely in English. The articles were excluded if they met any of the following exclusion criteria: (a) Population with any pathology or illness; (b) Repeated article; (c) Does not include any of the ratios or does not provide data with which they can be calculated. Conflicts between the two researchers in terms of this analysis were debated to unify the criteria; and a third researcher resolved any issues for which consensus was not reached.

The level of evidence was established following the guidelines of the "Dutch Institute for Healthcare Improvement" (CBO)[34]. The results are displayed in Table 1.

The data that was extracted for each study was as follows: characteristics of the sample and of the intervention protocols (Table 1), procedures in the isokinetic tests (Table 2) and results in the tests applied in each investigation (Tables 3 and 4).

Table 1. Features of the sample, intervention protocols and level of evidence.

Study	Year	Features of the sample				Protocol of Intervention	Level of Evidence
		Size sample (n)	Age (years) and gender	Height (cm)	Weight (kg)		
Castelo-Oliveira *et al.*[45]	2009	16 (M)	22 ± 2.6	173.8 ± 27.9	79.6 ± 10.3	Treadmill run	C
Cohen *et al.*[35]	2015	9 (M)	25.3 ± 0.8	178.8 ± 2.9	77.0 ± 3.7	LIST	C
Coratella *et al.*[11]	2014	22(M)	20.1 ± 2.4			LIST	C
Delextrat *et al*[36]	2013	14 (F)	26.1 ± 4.6	168 ± 12	62.7 ± 5.5	LIST (modified)	C
Delextrat *et al.*[46]	2012	9 (F)	24.3 ± 4.1	173 ± 7.9	65.1 ± 10.9	Standard week	C
Greco *et al.*[41]	2013	22 (M)	23.1 ± 3.4	178.0 ± 8.0	73.4 ± 7.4	PEIEF	C
Jones *et al.*[38]	2015	20 (M)	21.8 ± 2.3	172.1 ± 6.2	68.4 ± 9.1	$SAFT^{90}$	C
Koller *et al.*[44]	2006	16 (14M-2F)	41		79	Marathon	C
McIntyre, *et al.*[39]	2012	10 (M)	28 ± 7		79 ± 5	Sub-maximum test exercise bike	C
Olyaei *et al.*[43]	2006	32 (M)	24.89 ± 4.5		67 ± 8	IP	C
Rahnama *et al.*[9]	2010	13 (M)	23.3 ± 3.9	178 ± 0.05	74.8 ± 3.6	PEIEF	C
Small *et al.*[47]	2010	16 (M)	21.3 ± 2.9	185 ± 8.7	81.6 ± 6.7	$SAFT^{90}$	C
Wrigth *et al.*[33]	2009	8 (M)	22 ± 2.3		85 ± 3.3	IP	C

Note. Average Values ± Standard deviation; LIST; *Loughborough Intermittent Shuttle Test;* PEIEF: Soccer-Specific Intermittent Exercise Protocol; IP; Isokinetic Protocol; M: Male; F: Female; C: Non Comparative Studies (Evidence levels based on the indications of the CBO)

Table 2. Isokinetic Test Characteristics.

Study	Warm-up	Range of Movement	Leg	Con_Q	Con_H	Ecc_H	Rec.(min)	A.S.(rad*s^{-1})
Castelo-Oliveira, *et al*[45]	5' on exercise bike at 70W	70º		5	5	5	5	1.05 3.14
Cohen *et al.*[35]	10' exercise bike at 70W 2 x 30" static stretch H and Q	10º-90º	Dominant	2x5	2x5	2x5	2	2.09
Coratella *et al.*[11]			Both	3	3	3	2	1.05 3.14 5.24
Delextrat *et al.*[36]	10' exercise bike, with 5 sprints at the last 2'	0-90º	Both	5	-	5	2	2.09
Delextrat *et al.*[46]	30' jogging, basketball-specific movements, accelerations and active stretches		Dominant	3	3	-		1.05
Greco *et al.*[41]		70º	Dominant	5	5	5	5	1.05 3.14
Jones *et al.*[38]	5' on exercise bike at 60 W		Both	3	-	3	0.3	1.05
Koller *et al.*[44]	10' exercise bike	0º-110º	Both	4	4	4		1.05
McIntyre *et al.*[39]		90º	Dominant	3	3		1	3.14
Olyaei *et al.*[43]	5' (undefined)	10º-90º	Both					2.09
Rahnama *et al.*[9]	5' exercise bike at 60 revolutions*min-1, 10' static stretches and 2 sub-maximum repetitions	0º-90º	Both	3	3	3	1	1.05 2.09 5.24
Small *et al.*[47]	5' exercise bike at 60 W, 5' stretches static and dynamic, 5' jogging getting used to the SAFT	0º-90º	Dominant	3	3	3	1	2.09
Wrigth *et al.*[33]	5' treadmill, stretches and 5 repetitions sub-maximums	10º-90º	Dominant	5	5	5	0.1	2.09

H: Hamstrings; Q: quadriceps; Con_Q: number of maximum repetitions in concentric contraction of the quadriceps; Con_H: number of maximum repetitions in concentric contraction of the hamstrings; Ecc_H: number of maximum repetitions in eccentric contraction of the hamstrings; Rec.(min): recovery between series in minute; A.S: Angular Speed.

Table 3. Result of the H:Q Ratio and DCR for the dominant leg.

Study	A.V. (rad*s-1)	H:Q Ratio		DCR		Effect	Variation (%)	
		Pre	Post	Pre	Post		H:Q Ratio	DCR
Castelo-Oliveira *et al.*[45]	1.05	0.51	0.52	0.78	0.77	X		
	3.14	0.67	0.68	1.14	1.05	⇓+		-8
Cohen *et al.*[35]	2.09			1.11	0.98	⇓+		-12
Coratella *et al.*[11]	1.05	0.61 ± 0.07	0.60 ± 0.10	0.68 ± 0.07	0.66 ± 0.12	X		
	3.14	0.67 ± 0.07	0.68 ± 0.12	0.98 ± 0.14	0.88 ± 0.17	⇓+		-10
	5.24	0.69 ± 0.07	0.71 ± 0.15	1.29 ± 0.13	1.20 ± 0.20	⇓+		-7
Delextrat *et al.*[36]	2.09			0.85 ± 0.15	0.73 ± 0.13	⇓+		-14
Delextrat *et al.*[46]	1.05	0.75 ± 0.08§	0.69 ± 0.08			⇓*	-8	
		0.73 ± 0.06§	0.68 ± 0.06			⇓*	-7	
Greco *et al.*[41]	1.05	0.60 ± 0.06	0.58 ± 0.06			⇓*	-3.3	
	3.14			1.29 ± 0.2	1.16 ± 0.2	⇓+		-10
Jones *et al.*[38]	1.05			0.77 ± 13	0.77 ± 15	X		
	3.14			1.09 ± 20	0.98 ± 21	⇓+		-10
Koller *et al.*[44]	1.05	0.71	0.74	0.85	0.85	X		
McIntyre, *et al.*[39]	3.14	0.62 ± 0.09	0.77 ± 0.03			⇑*	24	
Olyaei *et al.*[43]	2.09			1.11	1.07	X		
Rahnama *et al.*[9]	1.05	0.54	0.53			X		
	2.09	0.62 ± 0.11	0.56 ± 0.09	0.77 ± 0.13	0.67 ± 0.12	⇓**	-10	-13
	5.24	0.80 ± 0.09	0.75 ± 0.07			⇓*	-6.3	
Small *et al.*[47]	2.09	0.60	0.58	1.16	1.00	⇓+		-15
Wrigth *et al.*[33]	2.09	0.62-0.90¶	0.85-1.23¶	0.78-1.00¶	0.95-1.23¶	X		

Note. A.S: Angular speed; DCR *Dynamic Control Ratio* (H_{ecc}/Q_{con}); H:Q ratio: H_{con}/Q_{con} ; X: with no significant effect on DCR and H:Q ratio; ⇓+ : significant decrease only of the DCR (p<0.05); ⇓*: significant decrease only of the H:Q ratio (p<0.05) ; ⇑*: significant increase only of the H:Q ratio (p<0.05); ⇓** : Significant decrease of the DCR and the H:Q ratio (p<0.05);§: data corresponding to the 5th and 6th day of applying the fatigue inducing protocol in this study, both measured at the same angular speed: 1.05 rad*s-1; ¶: results expressed in oscillations of the values according to the authors.

Table 4. Result of the H:Q Ratio and DCR for the non-dominant leg.

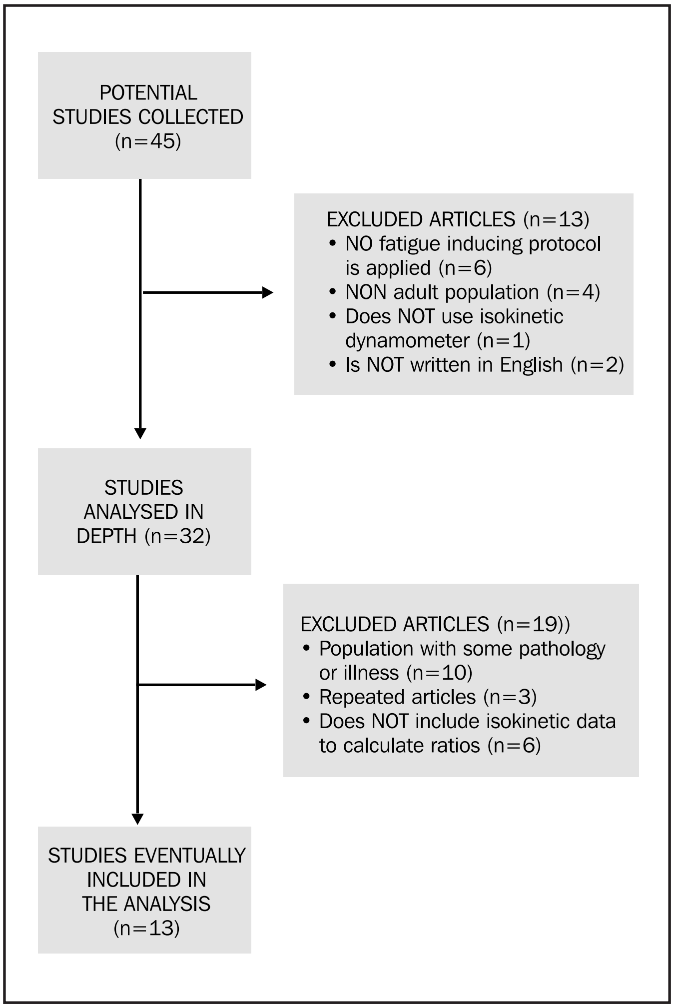
Study	A.S. (rad*s-1)	H:Q Ratio		DCR		Effect	Variation (%)	
		Pre	Post	Pre	Post		H:Q Ratio	DCR
Coratella *et al.* [11]	1.05	0.59 ± 0.06	0.58 ± 0.08	0.68 ± 0.09	0.64 ± 0.10	X		
	3.14	0.64 ± 0.09	0.66 ± 0.11	0.93 ± 0.11	0.87 ± 0.17	X		
	5.24	0.69 ± 0.11	0.71 ± 0.14	1.29 ± 0.16	1.23 ± 0.26	X		
Delextrat *et al.*[36]	2.09			0.88 ± 0.17	0.81 ± 0.15	⇓+		-8
Koller *et al.* [44]	1.05	0.73	0.78	0.89	0.91	X		
Olyaei *et al.*[43]	2.09			1.02	1.03	X		
Rahnama *et al.*[9]	1.05	0.58 ± 0.07	0.56 ± 0.06			⇓*	-3	
	2.09	0.62	0.59	0.75	0.68	X		
	5.24	0.79	0.75			X		

Note. A.S: Angular speed; DCR *Dynamic Control Ratio* (Hecc/Qcon); H:Q ratio: Hcon/Qcon; X: with no significant effect on the DCR and H:Q ratio; ⇓+ : significant decrease of the DCR (p<0.05); ⇓* : significant decrease of the H:Q ratio (p<0.05).

Characteristics of the sample and of the intervention protocol

Seven studies performed three protocol types based on the simulation of the activity performed in a football match. Three[11,35,36] applied the *Loughborough Intermittent Shuttle Test* (LIST)[37], two[38,39] used the SAFT9040, and a further two[9,41] carried out a soccer-specific intermittent exercise protocol (PEIEF)[42]. Furthermore, two of them[33,43] carried out isokinetic protocols; and a further four performed a marathon[44], a

Figure 1. Flow chart of the selection procedure for review studies.



continuous running protocol on a treadmill[45], a sub-maximum test on an exercise bike[39], and a quantification of the training load of a week of normal basketball training[46].

Isokinetic Test Characteristics

Table 2 displays the characteristics and conditions of the isokinetic tests. Four different angular speeds were used in the different joints that were included in this review. Six studies[9,11,38,41,45,46] performed their measurements at 1.05 $rad*s^{-1}$ (60º/s); seven[9,33,35,36,43,44,47] at 2.09 $rad*s^{-1}$ (120º/s), five[11,38,39,41,45] at 3.14 $rad*s^{-1}$ (180º/s) and two[9,11] at 5.24 $rad*s^{-1}$.

In addition, seven only assessed the dominant leg[33,35,39,41,45-47], defined as the one used to kick a ball, and five assessed both legs[9,11,36,43,44].

Results

The results obtained following the analysis of the studies collected in the review are displayed in Tables 3 and 4.

Figure 2. Overview of significant differences.

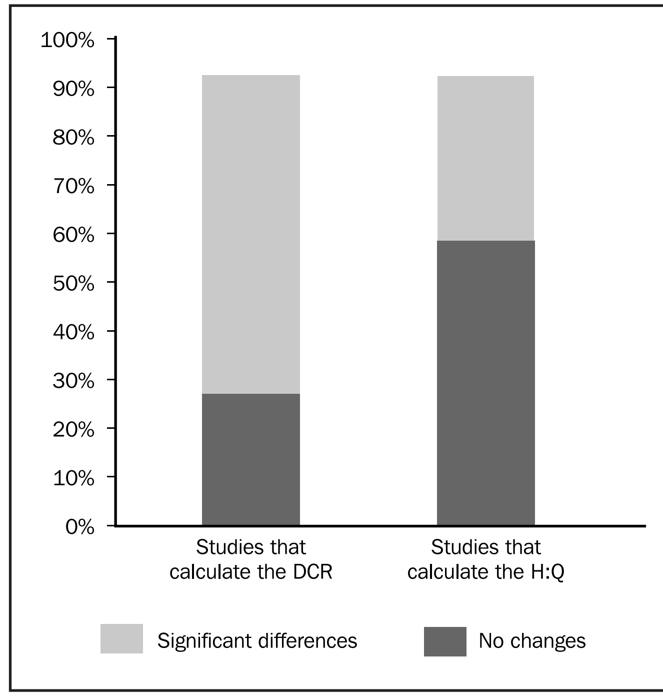
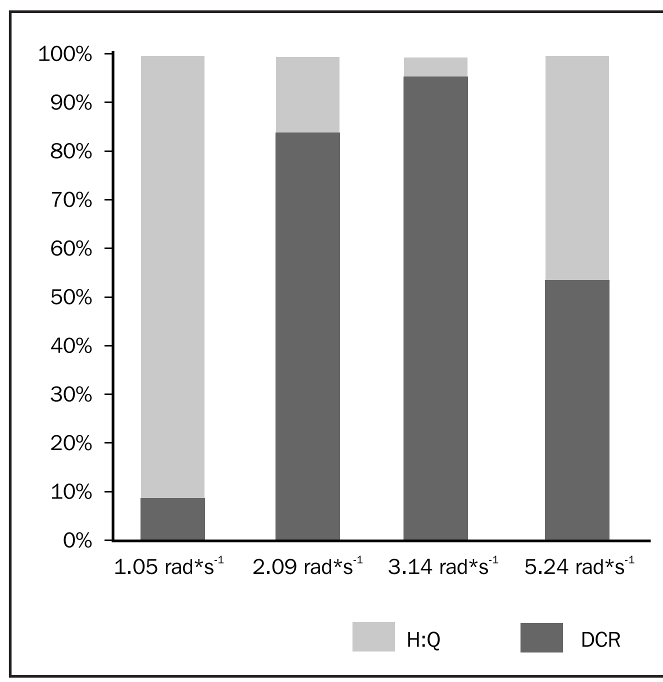


Figure 3. Decreases in the values in both ratios by speeds.



Dominant leg

This analysis reveals that more studies were found that discovered significant reductions in the DCR values than in the H:Q ratio upon applying different fatigue protocols (Figure 2).

Furthermore, these decreases in the DCR were produced at higher angular speeds in comparison to the H:Q ratio, in which the majority of the decreases occurred at 1.05 rad*s^{-1} (Figure 3).

LIST, SAFT and PEIEF

The studies that applied soccer-specific fatigue protocols[9,11,35,36,38,41,47] were those in which the greatest decreases were registered, especially regarding the DCR (Table 3), in which all but the Coratella *et al*.[11] studies revealed significant decreases at different angular speeds. On the other hand, only three of the studies that calculated the H:Q ratio[9,41,47] suffered significant decreases after performing these protocols.

Isokinetic Protocols

With regards to the isokinetic protocols, none of the two studies found significant differences in the DCR or the H:Q ratio in demographics made up of amateur footballers[33,43].

Others

The Castelo-Oliveira *et al.*[45] study assessed both ratios at different angular speeds before and after performing a fatigue protocol on a treadmill on subjects that were physically active but that did not practise any particular sport. However, only one significant decrease in the DCR was discovered, assessed at 3.14 rad*s^{-1}.

McIntyre *et al.*[39] checked the effects of a fatigue protocol on an exercise bike on the H:Q ratio, assessing an angular speed of 3.14 rad*s^{-1}. The results obtained in this study reveal a significant increase of 24% of the H:Q ratio, something that contrasts with the results of the other articles analysed in this review.

Finally, two articles by Delextrat *et al.*[46] and Koller *et al.*[44] studied the variation of the H:Q ratio and DCR before and after each normal training session of a basketball team, and after a marathon respectively. The data revealed that for the first study, significant differences in the H:Q ratio before and after training were only registered on the 5th and 6th days. Koller *et al.*[44] assessed the H:Q ratio and the DCR at an angular speed of 2.09 rad*s^{-1}, but no significant differences were obtained in the post-test in comparison to the initial measurement.

Non-dominant leg

Of the 13 articles analysed in this review, only 5 included the assessment of the non-dominant leg in the assessment of lower body strength (Table 2); and only two of them revealed significant differences after applying the corresponding protocol. Specifically, Delextrat *et al*.[36] discovered a decrease of almost 8% in the DCR at 2.09 rad*s^{-1} after performing the LIST; whilst in the results provided by Rahnama *et al.*[9] there is a decrease of 3% in the H:Q ratio after performing the PEIEF.

Discussion

The aim of this review was to analyse and check how fatigue affects two of the most used indicators in estimating the risk of suffering from an injury: the conventional ratio (H_{con}/Q_{con}) and the functional ratio (H_{ecc}/Q_{con}).

The recent research explains the decrease in the values of both ratios as the consequence of the great effort made by the hamstrings when controlling movement in running, and in the stabilisation of the knee joint during contact of the foot with the ground[9], which provokes high levels of fatigue in this muscle complex and a reduced capacity of maximum elongation of the muscle[48,49]. Other studies have revealed that the hamstring muscle complex suffers from the most fatigue during quick changes that occur from the eccentric phase to the concentric phase of a contraction, such as those that occur when kicking a ball or sprinting[25,50,51]. Furthermore, it has been shown that the greatest level of fatigue is reached towards the end of the game[52], and it is estimated that around 26% of injuries through strain occur in the final 15 minutes of a match[31]. The study by Cohen *et al.*[35] reveals a deterioration in the production of strength and deceleration capacity in the hamstrings related to the production of strength of the quadriceps in joint angulation at which hamstrings are more likely to suffer an injury. This angulation corresponds to the moment near full extension[53]. The explanation behind the low vulnerability of the quadriceps in terms of suffering an injury compared to the hamstrings in sports such as football, is that the specific actions of this sport represent considerable strength training for this muscle group, and therefore normal training provides a series of neuro-muscular adaptations against fatigue that do not occur with the hamstrings[9]. Another reason why the hamstrings and quadriceps do not tire the same way is down to the composition of the fibre types in each, which has proven to be very different[52]. The hamstrings tend to have a greater number of quick contraction fibres (type II) compared to the quadriceps[54,55]. These fibres have a greater tendency to become fatigued in comparison to slow fibres, and they do so earlier, which is why the hamstrings present a greater risk of suffering this type of fatigue-induced injury[7].

On the other hand, muscles are more likely to suffer from injuries during their eccentric phase, especially the hamstrings[7,17]. In the H:Q ratio, both muscles are assessed in concentric contractions, which is why recent studies suggest that the DCR is more effective in estimating the risk of suffering from a muscular injury, as the eccentric phase is considered[25,36,56,57]. In our review, the majority of the studies analysed that found significant differences after applying any fatigue protocol, in great measure, were done so in the DCR compared to H:Q (Figure 2).

Three studies[11,35,36] assessed the effect of fatigue provoked by a Test that includes the physical and physiological demands of football: LIST. All of them found significant decreases in the values of the DCR. Based on these results, Delextrat *et al.*[36] suggest the need to implement prevention methods based on the measurement of the decompensation between the hamstrings and quadriceps and in the application of programmes targeted at working on the eccentric phase of the hamstrings.

The peak eccentric torque of the hamstrings, and consequently the DCR also experienced a significant reduction as a result of the application of two fatigue protocols based on football: the SAFT[38,47] and

PEIEF[41,9]. This indicates that the eccentric strength of the hamstrings is reduced to decelerate the lower limb, especially at the end of periods in which the tests were divided. For this reason, the authors suggest the establishment of injury prevention strategies to reduce the impact of fatigue on the functional capacity of the hamstrings.

In terms of protocols to induce more non-specific fatigue, Castelo-Oliveira *et al.*[45] obtained significant differences by applying an on-going treadmill run and assessing subjects at a speed of 3.14 rad*s^{-1}. These authors attribute the decrease of the DCR to muscular damages caused by exercise in the contractile system, as given that no significant differences were found between the activation of agonist and antagonist muscle groups, the possible effects of neural transmission were ruled out[45]. Two isokinetic protocols were also carried out in which no significant changes were observed to the DCR between the pre and post[33,43]. The authors attribute this result to the nature of the protocol in terms of the intensity of the exercise, environment and nature of the load in question, variables that have proven to be capable of influencing fatigue mechanisms[58]. Finally, no significant changes were found in the DCR in a study in which the isokinetic strength of the lower body was assessed before and after running a marathon[44].

With regards to the H:Q ratio, this has traditionally been used to determine the risk of injury[18] when assessed at a speed of 1.05 rad*s^{-1}[27]. However, in our review, just five of the nine articles that calculated the H:Q ratio did so at this speed. And among them, only two found significant differences after applying a fatigue protocol[41,46]. Furthermore, the decrease percentages of the H:Q ratio were less in comparison to those of the DCR (Tables 3 and 4). Delextrat *et al.*[46] assessed the strength of the lower body before and after each female basketball training session. The H:Q ratio values decreased significantly by 8% and 7% just in the last two days of the week in which the measurements were taken. These results align with a study that determined the reduction of working capacity in a female basketball team after finishing a game[59]. Greco *et al.*[41], for their part, obtained a decrease of 3% after applying a PEIEF. However, Rahnama *et al.*[9] applied this same protocol and the significant differences were obtained for higher angular speeds. The main difference between both studies is in the demography used. Greco *et al.* use a semi-professional demographic, whilst Rahnama *et al.* assessed amateur footballers, for which the contrary results may be due to the difference between one group and the other. The studies by Coratella *et al.*[11] and by Castelo Oliveria *et al.*[45] also failed to find significant differences in the H:Q ratio after performing the LIST and an on-going treadmill run as fatigue protocols, at any of the angular speeds assessed. Nor were any significant results found in the H:Q ratio in three studies that assessed the isokinetic strength of the lower limbs at a speed of 2.09 rad*s^{-1}[33,44,47]. The protocols used were the SAFT, an isokinetic protocol, and the running of a marathon. Finally, one last study calculated the H:Q ratio after applying a prolonged test on an exercise bike until exhaustion, where the ratio values revealed a 24% increase[39]. The authors justify this result with another study in which it is concluded that a specific pedal strength may increase the point of strength on the joint on the knee flex[60], which may be the cause of this increase.

Of all the studies included in the review, only five included the assessment of the non-dominant leg. One of them found a decrease of 8% in the DCR after performing the modified LIST[36], and the other, a slight decrease of 3% in the H:Q ratio[9]. They are the only two studies analysed that reveal a significant decrease in the non-dominant leg. Coratella *et al.* found no significant decrease in any of the three speeds assessed, or in the H:Q ratio or in the DCR[11]. Neither did Koller *et al.*[44], Olyaei *et al.*[43] and Rahnama *et al.*[9]. Koller assessed both the H:Q ratio and the DCR, whilst Olyeaei *et al.* only assessed the DCR. Rahnama *et al*. only found a decrease in the H:Q ratio at 1.05 rad*s^{-1}, but for the other speeds assessed (2.04 and 5.24 rad*s^{-1}) and for the DCR, no significant changes were found. These results are explained as the dominant leg is frequently used in stopping and direction changes, as well as for dribbling and kicking the ball in matches. It has been shown that these actions have a greater energy expenditure when compared to just running, which is what the non-dominant leg would do[61] and therefore this may justify the results found in this review for the non-dominant leg.

Conclusions

Fatigue produces a reduction of the H:Q ratio and DCR values, which translates as a lessened capacity to produce strength in the lower limbs, especially in the hamstrings, and the consequential increased risk of suffering from an injury.

The DCR seems to be a more reliable indicator than the H:Q ratio as it considers the eccentric phase of the hamstrings, where there is a greater risk of suffering from an injury if the muscle is fatigued or weakened.

The most specific protocols provoked greater fatigue in the hamstring muscle group and the quadriceps, and consequentially a greater decrease in the values of both ratios compared to laboratory tests. Therefore, future research should consider a match or real test as an element that induces fatigue.

The dominant leg suffered greater decreases in terms of recovering strength, and as a result, greater decreases of the H:Q ratio and especially the DCR. This could mean that greater fatigue is produced in this limb in comparison to the non-dominant leg through the actions performed more by one than by the other: kicking a ball, starting the direction change or starting the sprint. This is why comparative work should be carried out to try and correct these imbalances and fatigue rate in the dominant leg.

Based on the results obtained from the different studies included in this review, the injury prevention strategies should focus attention on the one hand on strengthening the hamstrings, mainly during the eccentric phase, which is when the greatest risk of suffering from an injury is concentrated. And on the other hand, in slowing the appearance of fatigue to avoid imbalances in recruiting strength from both muscle groups of the lower limbs, but especially in the hamstrings.

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