Original article

Links between Eccentric Hamstring Strength and a History of Lower Limb Injury in Colombian High-performance Athletes

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Summary

The main cause of injury in athletes is of muscular origin and of all those of the hamstrings it is the most important. The inadequate eccentric strength of these is a factor that is related to lower limb injuries. At the Sports Science Center of the Ministry of Sports, the eccentric strength of the hamstrings is evaluated with the Nordic test. In Colombia, it is not known if this is related to lower limb injuries in the different world-class high-performance athletes who attend there. A descriptive work was proposed with a quantitative approach and analytical phase, evaluating the pre-participation medical records of 195 athletes who underwent the Nordic test during the year 2021. The athletes analyzed were 56% men, with ages for both sexes on average of 21.5 years, with body mass indexes of approximately 22.1 k/m^2. The most frequent injury to the lower limbs was muscle (38.5%), followed by tendinopathies (27%). Of the muscle, the hamstrings were injured in 69%. An average maximum force was found for all athletes of 292.4 ± 67.06 N and a relative force of 4.52 ± 1 N/kg. The bivariate analyzes show an association between the presence of injury and lower maximum eccentric hamstring strength for both sexes. Furthermore, it was found that asymmetries less than 15% of the maximum eccentric hamstring strength were associated with a lower presence of injury. From a multivariate analysis, normative reference curves were constructed for weight, sex, and maximum eccentric strength of these athletes. It contributes to the conceptual gap of the behavior of eccentric hamstring strength and its relationship with the presence of lower limb injuries in different Colombian elite athletes.

Key words:
Sports. Performance. Leg injuries. Hamstrings. Strength. Eccentric.

Asociación entre la fuerza excéntrica de isquiotibiales con historia de lesión en miembros inferiores de atletas colombianos de alto rendimiento

Resumen

La principal causa de lesión de los deportistas es de origen muscular y de todas la de los isquiotibiales es la más importante. La inadecuada fuerza excéntrica de éstos es un factor que se relaciona con lesión de miembros inferiores. En el Centro de Ciencias del Deporte del Ministerio del Deporte se evalúa la fuerza excéntrica de los isquiotibiales con el test Nórdico. En Colombia, no se sabe si esta se relaciona con lesión de miembros inferiores en los diferentes deportistas de alto rendimiento de talla mundial que allí asisten. Se planteó un trabajo descriptivo con enfoque cuantitativo y fase analítica evaluando las historias clínicas preparticipativas de 195 deportistas a los que se les realizó el test Nórdico durante el año 2021. Los deportistas analizados 56% fueron hombres, con edades para ambos sexos en promedio de 21,5 años, con índices de masa corporal de aproximadamente 22,1 k/m^2. La lesión más frecuente en miembros inferiores fue la muscular (38,5%), seguida por las tendinopatías (27%). De la muscular, los isquiotibiales se lesionaron en el 69%. Se encontró un promedio de fuerza máxima para el total de deportistas de 292,4 ± 67,06 N y una fuerza relativa de 4,52 ± 1 N/kg. Con los análisis bivariados se evidencia una asociación entre la presencia de lesión y menor fuerza máxima excéntrica de isquiotibiales para ambos sexos. Además, se encontró que las asimetrías menores al 15% de la fuerza máxima excéntrica de isquiotibiales se asociaron con menor presencia de lesión. A partir de un análisis multivariado se construyeron las curvas de referencia normativas para peso, sexo, fuerza excéntrica máxima de estos deportistas. Se aporta al vacío conceptual del comportamiento de la fuerza excéntrica de isquiotibiales y su relación con la presencia de lesión de miembros inferiores en diferentes atletas élite colombianos.

Palabras clave:
Deportes. Rendimiento. Lesión de extremidades. Isquiotibiales. Fuerza. Excéntrica.

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Introduction

Skeletal muscle tissue in non-athlete humans accounts for 40-50% of body weight in men and 25-35% in women. However, this figure is usually far higher in athletes and, in weightlifters, can reach up to 65%[1]. Athletes are highly susceptible to injury due to their number of daily training or competition hours, and muscle is the most commonly compromised tissue[2,3]. That said, the susceptibility of each muscle group will depend on the characteristics and demands of the specific sport being practised[2,4,5].

Muscle injury in athletes is associated with numerous risk factors. It occurs in the lower limbs for a sizeable proportion of athletes, mainly the hamstrings, and significant attention is given to this matter due to the high incident rates and prevalence. In light of the above, hamstring muscle injury (HMI) has aroused strong interest in the scientific community due to the evidence pointing to especially high occurrence in team sports[3,6,7]. This type of injury accounts for 12% of all injuries reported by 17 teams of the various European football (soccer) leagues during the first decade of this century[6]. More recently, that figure doubled to 24% for the seasons running from 2016-202[18]. Furthermore, it accounts for 16% in rugby[9] and 13% in Australian football[10]. For the various sports clubs involved, this represents a high financial cost due not only to the rehabilitation and salary of players but also to the lack of availability in these athletes at key moments because they are unfit to play due to injury[6]. In addition, a recurrence rate of up to 18% has been reported at two months[8], which only aggravates the problem.

Because it is a multicausal event, answers are sought to the questions of how and to what extent for each sport and population group certain risk factors may impact most heavily. A lack of eccentric strength is one of those factors, as it has been identified as creating a risk of muscle injury; especially in those sports with high intensity running requirements such as football[11] (soccer) and basketball[12]. Various devices currently exist for the assessment of eccentric hamstring strength that exceeds the limitations of isokinetic dynamometry[13]. One of them is the NordBord from VALD Performance®. With the Nordic hamstring exercise, the device can register the maximal eccentric hamstring strength and the imbalance between limbs with an assessment time of less than five minutes per athlete. Although this device is a reliable measure of eccentric knee flexor strength during Nordic hamstring exercise[13], no literature currently exists that examines whether the measurements produced by this device predict future HMI risk in an athlete. Nonetheless, it is recognised as a factor that reduces injury[14] when training with this exercise.

Nordic exercise used to work the hamstrings eccentrically is currently one of the most closely studied exercises in literature, establishing it as a suitable exercise for HMI prevention[14,15] and it could be reasonably expected that the measurement of eccentric hamstring strength during this exercise can provide information on HMI risk in the future.

Finally, this study sought to determine whether the magnitude of eccentric hamstring strength and imbalance thereof between limbs is associated with a history of injury in high-performance athletes in different sports. Furthermore, it also sought to determine the benchmark values for eccentric strength in this population type. The main hypothesis was that the athletes who suffered an HMI would show lower levels of strength and greater imbalance between the limbs in terms of eccentric hamstring strength when compared with their counterparts with no history of such injury.

Material and method

A retrospective study is proposed under a quantitative approach with an analytical stage that was approved by the ethics committee of the National University of Colombia in minutes 018-165 of 29 September 2021. All the preparticipation assessments conducted on high-performance athletes attending the Sports Science Centre of the Colombian Ministry of Sport between 1 January and 30 November 2021 were analysed.

Of the 350 preparticipation assessments, 198 records were selected as they included a detailed history of injury, complete results from the Nordic test and the medical diagnosis reached by an orthopaedic and/or sports medicine professional in those athletes with a history of injury.

Assessment of Eccentric Hamstring Strength

The assessment of eccentric hamstring strength was determined via the NordBord Hamstring Testing System from VALD® Performance. Participants knelt on the NordBord platform with their ankles secured immediately over the lateral malleolus using individual ankle braces that link to uniaxial load cells on the device. Following a warm-up series, participants performed a series of three maximal repetitions of the Nordic exercise, with 20-second rests between the various attempts. The athletes were told to gradually lean forwards as slowly as possible while resisting this movement as much as possible with both legs, maintaining their core and hips in a neutral position and their hands crossed over their chest[13]. Participants were vocally urged to make the maximum effort in each repetition. A test was considered acceptable when the production of force reached a defined peak (indicative of maximum eccentric strength), followed by a rapid reduction in force, which would occur when the athlete could no longer apply or generate more force.

Data Analysis

The data on eccentric hamstring strength for each limb were exported from the online platform of VALD Performance® where peak strength for the three repetitions of each limb (left and right) was identified. Eccentric hamstring strength was reported in absolute terms (N) and in relative terms vis-à-vis body mass (N·kg-1), helping to determine an average of the maximum force levels in the three repetitions for each limb[13].

The imbalance between limbs in terms of eccentric hamstring strength was calculated as a proportion of the force differences between the limbs (left and right). This was carried out using the method recommended by Impellizeri, *et al*.[16]. A negative percentage imbalance indicated that the left limb was stronger than the right, while a positive percentage indicated the opposite.

Statistical analysis

Central tendency and dispersion measurements were determined for those variables of a quantitative nature and frequency distributions for those variables of a categoric or qualitative nature, all with their respective confidence intervals of 95%. A bivariate analysis was conducted to compare age, height, weight, limb imbalance percentage and eccentric strength between athletes with and without a history of injury. The T student and Mann–Whitney U statistics were used to determine the differences based on the distribution of the data for analysis, which were determined using the Kolmogorov-Smirnov statistic.

The magnitude of effect for the differences revealed was calculated using the Cohen's D statistic, which was determined using G Power software version 3.1. The following convention was used for analysis: values below 0.2 were considered to reflect no effect; between 0.21 and 0.49 reflect a small effect; between 0.5 and 0.7 indicate a moderate effect; and, finally, values over 0.8 indicate a major effect[17].

Finally, the benchmark values proposed in this study were constructed from the Box-Cox Cole and Green (BCCG) distribution using the method known as minimums squared[18], which can be found in the library of additive models generalised by location, scale and form[19] in the R Studio statistics software.

Results

The characteristics of the athletes who were assessed can be found in Table 1. In short, the sample mostly consisted of male athletes aged on average 21 + 4.6 years, with an average height of 171.9 + 9.5 centimetres, an average weight of 65.7 + 12.8 kilograms and a body mass index (BMI) of 22.1 + 3 kg/m^2.

Different sports were included in the analysis. However, athletics, volleyball and ultimate (73.7%) accounted for the majority of the sample included in this study.

Finally, a history of lower limb injury was reported in 97 of the 198 preparticipation assessments reviewed, with muscle injury being the most prevalent (38.5%) followed by tendinopathies (27%).

Figure 1 shows the behaviour in terms of peak strength or maximum strength, relative maximum strength and asymmetry with regard to the history of injury and gender. It is clear that the male gender presents higher levels of strength and similar symmetry values when compared with the female gender. However, when disregarding this factor in terms of history of injury, it can be seen that both men and women show statistically significant differences in peak strength, thereby determining that the athletes with no history of injury present higher levels of strength than those with a history of lower limb injury. Nonetheless, when analysing relative strength, significant differences can only be seen in the male gender; revealing that the athletes presenting a history of injury perform worse in terms of strength when compared with those having no history. In contrast, when analysing asymmetry, it can be seen that significant differences exist in the female gender only, thereby showing that there is greater asymmetry in female athletes with a history of injury.

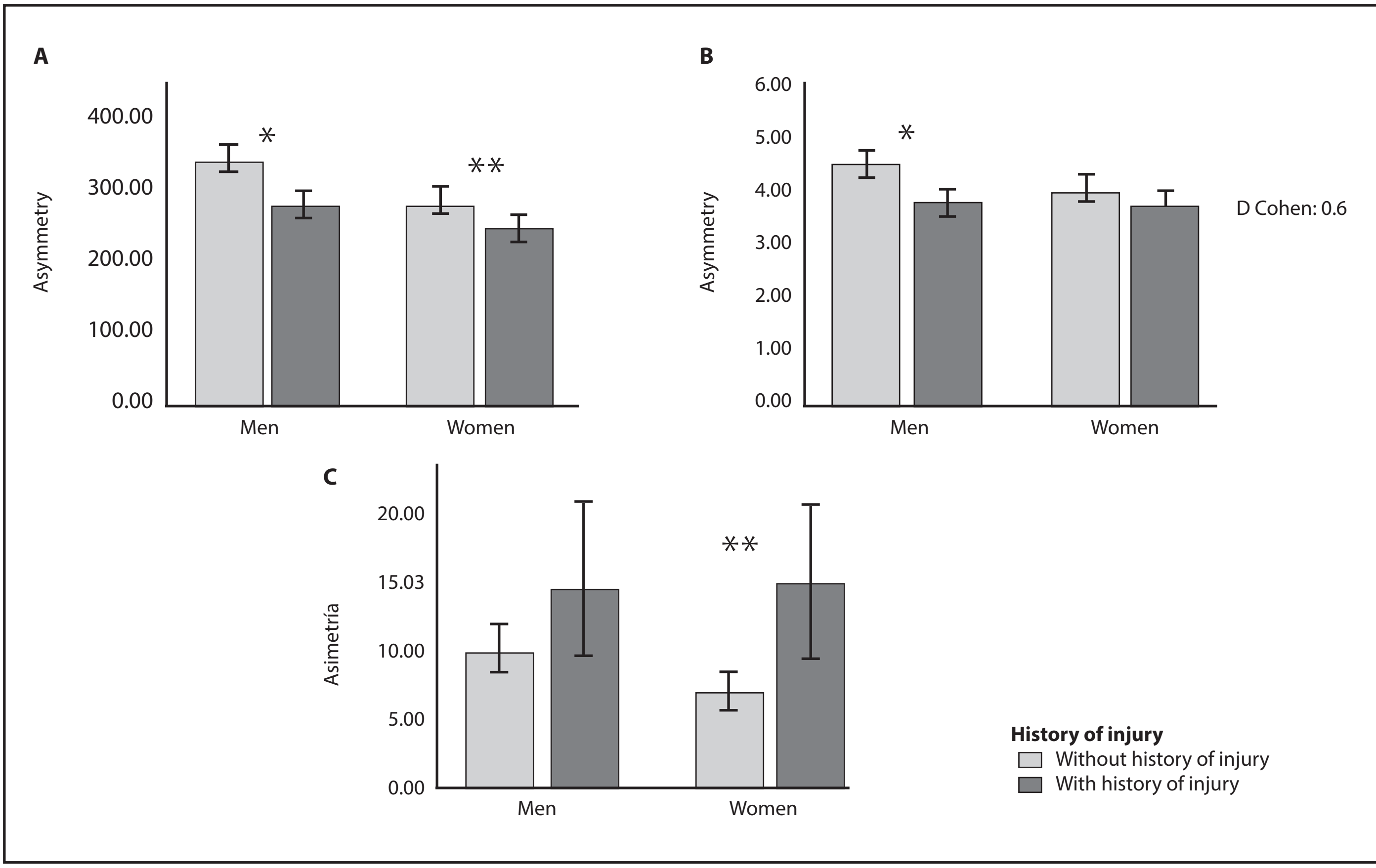
Table 2 shows the results obtained from the assessment of eccentric hamstring strength, the age and the BMI when taking the history of injury into account. An average maximum strength for all the athletes was determined at 292.4 + 67.06 N and a relative strength of 4.52 + 1 N/kg. However, it is worth noting that performance in strength (maximum strength, average strength across the three Nordbord test attempts and relative strength) is considerably lower in the athletes with a history of injury, observing worse performance results when compared with the athletes without a history of injury.

Table 1. Characteristics of the sample.

Variable		Frequency	%	CI 95%
Gender	Male	110	55.6	48.3 - 62.5
	Female	88	44.4	37.4 - 51.6
History of injury	Yes	97	49	41.8 - 56.1
	No	101	51	43.8 - 58.1
Dominance	Right	172	86.8	81.3 - 91.2
	Left	26	13.1	8.7 - 18.6
Type of injury	Bone	7	7.35	2.9 - 14.4
	Muscle	32	38.5	24.0 - 43.6
	Ligament	18	18.8	11.5 - 28.0
	Cartilage	8	8.3	3.6 - 15.7
	Tendon	26	27.1	18.5 - 37.1
Sport	Martial arts	1	0.5	0.01 - 2.7
	Athletics	76	38.4	31.5 - 45.5
	Basketball	1	0.5	0.01 - 2.7
	BMX	7	3.5	1.4 - 7.1
	Boxing	12	6.1	3.1 - 10.3
	Cycling	9	4.5	2.0 - 8.4
	Fencing	1	0.5	0.01 - 2.7
	Football	1	0.5	0.01 - 2.7
	Gymnastics	4	2.0	0.5 - 5.0
	Skating	2	1.0	0.12 - 3.6
	Weightlifting	9	4.5	2.0 - 8.4
	Squash	4	2.0	0.5 - 5.0
	Taekwondo	1	0.5	0.01 - 2.7
	Ultimate	41	20.7	15.2 - 27.0
	Volleyball	29	14.6	0.01 - 2.7

Source: Authors.
%: percentage; IC 95%: Confidence interval at 95%.

Figure 1. Comparison of eccentric strength and asymmetry with history of injury and gender. 1A. Comparison of maximum eccentric strength with history of injury and gender. 1B. Comparison of relative maximum eccentric strength with history of injury and gender. 1C. Comparison of asymmetry with history of injury and gender.



Source: Authors
*Indicates statistical significance for the Mann-Whitney U test statistic; **Indicates statistical significance for the T student statistic; Cohen's D: Magnitude of effect for the statistical differences.

Table 2. Strength characteristics based on history of injury.

Variable	With a history of injury			Without a history of injury			P value	Cohen's D	Total		
	Average	SD	CI 95	Average	SD	CI 95			Average	SD	CI 95
Maximum strength (N)	267.3	50.29	257.1 - 277.4	316.5	72.34	302.5 – 330.8	0.000**	0.78	292.41	67.06	283.0 - 301.8
Relative strength (N/kg)	4.2	0.89	4.0 - 4.3	4.8	1.01	4.6 - 5.0	0.000*	0.63	4.52	1.00	4.3 - 4.6
Average strength (N)	275.1	63.7	262.3 - 288.0	298.1	68.8	284.5 – 311.7	0.012**	0.34	286.91	67.22	277.4 - 296.3
BMI (kg/m^2)	22.0	2.8	21.5 - 22.6	22.1	3.2	21.5 - 22.8	0.854	0.003	22.11	9.57	21.6 - 22.5
Age (Years)	22.6	5.1	21.6 - 23.7	20.1	3.7	19.4 - 20.9	0.001**	0.56	21.41	4.6	20.7 - 20.0

Source: Authors.
*T student; **Mann-Whitney U test.
N: Newton; N/kg: Newton per kilogram of weight; CI 95: Confidence interval at 95%; SD: Standard deviation.

Table 3. Link between history of injury and asymmetry.

		History of injury		P value	RR
		With a history (%)	Without a history (%)		
Asymmetry	Asymmetry > 15%	20.6	9.9	0.035	1.45
	Asymmetry > 15%	79.4	90.1		

Source: Authors.
RR: Relative risk; %: Percentage.

Table 4. Benchmark values for maximum eccentric strength.

Benchmark values for men (N)							
Weight (kg)	**-3SD**	**-2SD**	**-1SD**	**0**	**1SD**	**2SD**	**3SD**
40 – 59	67.0	165.5	242.9	301.6	349.9	391.9	429.4
60 – 79	103.5	209.1	285.4	344.7	394.4	438.1	477.4
80 – 100	110.6	189.0	305.9	394.8	466.7	528.2	538.7
+ 100	115.5	196.6	352.6	473.6	570.1	651.8	723.7
Benchmark values for women (N)							
Weight (kg)	**-3SD**	**-2SD**	**-1SD**	**0**	**1SD**	**2SD**	**3SD**
40 – 59	123.3	166.9	209.4	251.0	292.0	332.3	372.2
60 – 79	119.7	175.1	228.7	281.0	332.4	383.0	433.0
+ 80	183.0	207.3	231.2	294.9	335.2	390.4	441.3

Source: Authors.
SD: Standard deviation; N: Newton; Kg: Kilograms.

Table 3 shows the asymmetry and history of injury variables, which present a statistically significant link. Based on the calculated relative risk (RR), it can be determined that having asymmetry of more than 15% is linked to having a history of injury. Hence, this result allows us to state that asymmetries of over 15% may become a risk factor for HMI in high-performance athletes.

As is common in this kind of studies, a combination of different processes was used that involve subjective reasoning, statistical analysis and a literary review to establish the various benchmark values for eccentric hamstring strength (cut-off points) in the population of high-performance athletes. Figure 2 shows the percentiles for maximum hamstring strength measured with the NordBord while considering the body weight of the athletes. These data were the basis for the benchmark values shown later.

After adjusting the data, the hyperparameters were determined and selected using the BCCG model, via which the values for eccentric strength according to body weight were standardised and predicted.

In light of the above, Table 4 shows the benchmark values in N discriminated by gender and determined according to the percentile behaviour of maximum eccentric hamstring strength in the sample assessed (Figure 2). For a better understanding of the results shown in the Table, it is proposed that the values located between +/- one SD be values considered as normal. Based on the above information, a male athlete of over 100 kg with a maximum hamstring strength of 300 N is proposed as an example. Based on the determined values, this athlete would be below normal performance of the population.

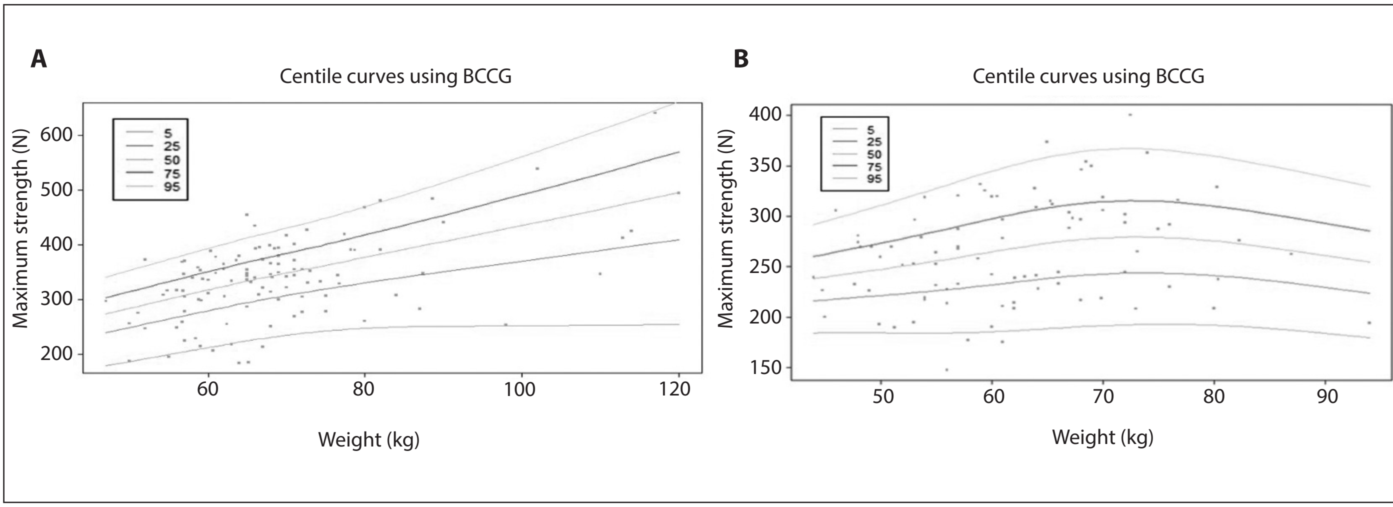
Discussion

This project was conducted with high-performance athletes forming part of the Colombian national teams for the period January-November 2021. The main findings were: firstly, that athletes with no history of injury present higher levels of strength when compared with those with a history of lower limb injury. Secondly, women with asymmetries of over 15% are those female athletes with a history of injury. Thirdly, that performance in strength (maximum strength, average strength across the three Nordbord test attempts and relative strength) is considerably lower in those athletes with a history of injury given that worse performance results were observed when compared with those athletes with no history of injury. Furthermore, by virtue of the need to have benchmark hamstring strength values in sports other than football, an initial approach is provided to benchmark tables for maximum hamstring strength in men and women for our population.

57% of all the assessments conducted in this period were taken into consideration. The others were mainly discarded due to errors in performing the Nordic exercise or due to incomplete information.

15 different sports are represented, with volleyball, ultimate and athletics accounting for 74.3%. It is worth mentioning that only one

Figure 2. Eccentric strength percentiles. 2A. Maximum eccentric strength percentiles for men. 2B. Maximum eccentric strength percentiles for women.



Source: Authors.
BCCG: Box Cox Cole and Green model.

footballer was assessed, thereby lending added relevance to this project because this is the sport in which the most studies on lower limb muscle injury are conducted[7] and even more so when considering that the small amount of information published in countries such as Colombia relates to football[20] (Table 1).

The athletes assessed in this study were young people with an average age of 21 + 4.6 years, with a balanced distribution in terms of gender similar to that reported in the study by Schmidt-Olsen, *et al.*[21]. The number of injuries in young footballers seems to increase with age. The 17-18 years age group seems to have a similar or even higher incident rate when compared with adults, this result coinciding with that reported by numerous authors[22,23]. The same finding was reported in a study of injuries during 12 international tournaments in players from different age and ability level categories[24]. Within this context, it can be seen that the famous "sport specialisation" in children and teenagers is linked to a greater risk of injury, with muscle injury remaining the most significant[25]. In light of the above, it is worth linking the age at which training begins in a single sport with the increase in risk of muscular injury and, more specifically, hamstring injuries in South American countries, where the development of this type of research in high-performance sport is precarious.

In this study, the main injuries were muscular (38.5%) (data not shown) as reported by, Alonso *et al.* (48%)[26] and Zahínos, *et al.* (2010)[27], among others, in football, where the highest frequency of injury was muscular, and up to 80% of the total, followed by joint, tendon and bone[27].

In this research, hamstring injury accounted for 69% of all lower limb muscle injuries; i.e. the most common by far. This has been clearly shown by numerous studies around the world and for many athletes[28], such as Judo[29], basketball[30], beach football[31], baseball[32], and, as stated above, football, where it continues to increase, which is why growing attention is being paid to the topic[8].

In terms of the physical qualities, strength and muscle power are the physiological basis for action in each muscle-bone unit. Furthermore, training these qualities increases performance and reduces the risk of injury in an athlete[33]. One of the main functions of the muscle group at the back of the thigh has been recognised as tied to the development of eccentric contraction. This type of contraction is associated with a higher risk of injury[34]. Describing and establishing the behaviour behind the causes of hamstring injuries through the assessment of eccentric strength will in turn help, to some extent, resolve one of the main causes of lower limb muscle injury for a good number of athletes.

The eccentric hamstring muscle strength in N that was found via the Nordic test was higher in men (328.48 N) than in women (260 N) (Figure 1). In men, it was similar to that reported by Quiceno, *et al*. in a professional football team (339 N) in Colombia[20].

A number of postulated risk factors exist for injury of muscular origin but few have been studied as in depth as strength. As stated above, strength is one of the physical qualities that, when trained, reduces the risk of injury and improves performance in athletes[35]. However, in the case of lower limbs, strength symmetry is another factor that is tied to injury[36]. Better tools are therefore needed that are capable of not only reporting unilateral strength but also bilateral strength so as to enable an ongoing assessment of the various expressions of strength and thus conduct adequate monitoring of an athlete over the course of a season.

Within these expressions of strength, maximum strength (the ability to provide maximum strength with a simple action and under specific conditions)[37] — which, for this project, was recorded using the Nordic test — has been recognised as a characteristic of strength susceptible to constant assessment and with sufficient evidence to be considered as an injury risk factor, such as is the case when it is diminished for a type of specialist sport and a type of athlete in particular. There is a large body of literature supporting the use of the Nordic test and one of the variables — maximum strength, obtained from the software — to assess hamstring muscles[12].

In this research, it was possible to establish that a history of weakness or asymmetric activation in hamstring strength was linked to injury in this same muscle group (Table 2). Other authors, such as Opar, *et al.,* 2013[13] and Lee, *et al.*, 2009[38] have been able to show how a reduction in maximum or isometric eccentric strength is tied to injury risk or re-injury in footballers. Similarly, asymmetry continues to be a factor that should be taken into consideration and should always be examined whenever lower limb muscle strength is assessed. It was possible to link asymmetry values of over 15% to injury.

Finally, an initial approach is offered for local athletes in various sports, with which a series of benchmark values was established for maximum eccentric hamstring strength (Figure 2, Table 4) using the internationally widespread Nordic test and from which a few measurements already exist, only for professional football in Colombia[20,39]. Producing benchmark values is always a challenge. However, the intention is to use athletes from the national teams as a model in order to enable the highly necessary assessment and evaluation process to be begun for monitoring athletes before, during and after the season.

This research provides a context for the complex dynamic model for injury in sport, in which changes to strength form part of the already recognised "predisposed athlete". It also seeks to highlight the relevance of engaging in local research to establish behaviours by the various factors in athletes, both intrinsic and extrinsic, which should be continuously monitored so as to underpin good performance by our high-performance athletes.

In conclusion, a suitable support process should be created among players, coaches and biomedical teams so that proper work can be done on the process to prevent muscle injury, which continues to be a major reason why a high number of training and competition hours are lost, in turn impacting the health of high-performance athletes.

More studies like this one are needed to develop high-performance sport, ranging from the reserves through to professional medallists.

Conflict of Interest

The authors declare no conflict of interest whatsoever.

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