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Isokinetic strength of the quadriceps and hamstrings in professional handball players

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ABSTRACT

The aim of this study was to evaluate the strength of the left and right hamstring and the quadriceps muscle group in professional handball players. It also aimed to assess the statistical significance of the relationship between these two muscle groups. The study included eight professional handball players from the "Borac" team, Banja Luka. Standard anthropometric measurements were taken. The following variables were assessed: maximum quadriceps torque (MQT), maximum hamstring torque (MHT), and hamstring–quadriceps ratio (HQR), to determine the presence of muscle imbalances bilaterally and unilaterally. Isokinetic testing of knee strength was performed on both knees at the Institute for Sports, Faculty of Physical Education and Sports, University of Banja Luka, using the CON-TREX CYK device, which allows comprehensive assessment of muscle and joint function. Based on the findings, there was no significant muscle imbalance in handball players, i.e., no significant difference in quadriceps or hamstring strength between the left and right legs, either bilaterally or unilaterally ($p > 0.05$). The strength of the left and right quadriceps and hamstrings showed minimal variation, with no evidence of muscle imbalance. In professional and elite sports, information from isokinetic diagnostics is essential for designing training programs and preventing injuries. This study provides normative data for the handball player population.

KEYWORDS

Handball; Isokinetic Testing; Hamstring; Quadriceps; Imbalance

1. INTRODUCTION

Handball is an Olympic sport and a complex team game in a limited space defined by rules and regulations. It is a very demanding poly-structural motor activity characterized by high intensity of movement and high energy consumption, rapid change of direction, maximum muscle strain, high pressure force on the surface, a large number of falls on the surface, a large number of faster ball throws, etc. All of the above require an exceptional level of technical and especially physical preparation from the player. As a result of these activities during matches, as well as the training process, there is a large number of injuries to the locomotor apparatus of handball players.

Handball has one of the greatest rates of injuries (82.2%) at the Olympic Games (Palmer et al., 2021). Most authors identify the biggest number of injuries in the lower extremities, highlighting the knee, thigh, and ankle joints. However, there is no consensus on which has the highest frequency. According to Vila Barreiro et al. (2022), shoulder injuries are the most common upper extremity injuries. A study conducted at the Men's Handball World Championship in Qatar (Bere et al., 2015) found that 58.3% of injuries were located in the lower extremities, mainly in the ankle, thigh, and knee, while 16.7% affected the upper extremities, mostly the shoulder and fingers/thumb. Another study conducted the same year found that the knee and shoulder had significant injury rates of 20% and 22%, respectively (Clarsen et al., 2015). Later studies (Aman et al., 2019; Florit et al., 2019; Rafnsson et al., 2019; Luig et al., 2020; Mashimo et al., 2021). A study by Tabben et al. (2019) found that the ankle joint (19.3%), head/face (17.3%), knee (15.1%), and thigh (12.9%) were the most injured body parts during the 2017 World Handball Championship in France.

Maximum leg strength was measured using a variety of techniques in past professional handball sports performance studies. The majority of these studies (Chaouachi et al., 2009; Haugen et al., 2016; Ortega-Becerra et al., 2018; Hermassi et al., 2019) used various forms of maximal squat tests to determine maximal leg strength. Only a small amount of evidence used isokinetic testing (Teixeira et al., 2014; Gonzalez-Rave et al., 2014).

For evaluating maximal knee quadriceps and hamstring strength and muscle imbalance, isokinetic is still regarded as the gold standard (Xaverova et al., 2015; Maurelli et al., 2019). While numerous studies measuring maximal isokinetic knee strength have been performed on women handball players (Lund-Hanssen et al., 1996; Andrade, 2012; Xaverova et al., 2015; Risberg et al., 2018), only few studies included male handball players (Teixeira et al., 2014; Gonzales- Rave et al., 2014; Maurelli et al., 2019).

When evaluating the physical performance and injury risk of handball players, the isokinetic muscle strength ratio between the hamstrings and quadriceps is a one of the more important factor. This ratio, commonly known as the hamstring quadriceps ratio (HQR), indicates a strength imbalance between antagonistic muscle groups surrounding the knee joint. Given the high incidence of hamstring injuries in sports requiring rapid acceleration and deceleration, maintaining a balanced strength ratio between both muscle groups is important for injury prevention and peak athletic performance, particularly in sports requiring quick direction changes, jumping, and explosive movements. To ensure dynamic stability of the knee and prevent unilateral and bilateral imbalances, the hamstring quadriceps ratio (HQR) is employed as a measure of the knee musculature's powers. Diagnosing muscle imbalances in professional athletes during the pre-season is crucial, since it is essential to follow an adequate exercise program to restore the hamstring quadriceps ratio to its expected levels. Also, if an injury occurs, it is vital to assess whether muscular imbalances exist and, if so, implement adequate rehabilitation. Muscle balance relationships change with joint and population. In healthy settings, the HQR is 60-69%, with the knee extensors being stronger than the flexors (Gerdijan et al., 2011). This threshold is important because it shows how well the hamstrings can balance the force that the quadriceps produce when moving at high speeds. Extensive research on the isokinetic strength profile of elite female handball players has shown that higher angular velocities during testing tend to enhance the hamstring quadriceps ratio. According to Xaverova et al. (2015), this phenomen is explained by the hamstrings' quicker muscle fiber composition than that of the quadriceps, which enables superior performance at higher speeds. Muscle strength has also been shown to change periodically; Maurelli et al. (2019) found that peak torque values for the quadriceps and hamstrings changed significantly during the competition season. According to their research, athletes may lose strength, especially at lower angular velocities, which could affect their performance and increase their risk of injury if proper training strategies are not implemented.

This emphasizes how crucial it is to include efficient warm-up exercises that help athletes maintain muscular balance in addition to preparing them for performance. Stretching is a common warm-up exercise for athletes to improve performance and prepare the body for practice or competition (Gerdijan et al., 2021). There is continuous discussion on the selection of stretching techniques for warm-ups (Shelton & Kumar, 2009). Additionally, Chen et al. studied the effect of warm-up protocols on the hamstring quadriceps ratio. They have shown that some warm-up techniques, like dynamic stretching and vibration foam rolling, can improve muscle performance and the HQR in female handball players (Chen et al., 2023). According to Gerdijan et al. (2017), static

and dynamic stretching both have beneficial short-term effects when used before activities involving a low contraction rate and high external resistance, but only dynamic stretching is beneficial when used before an activity involving a higher muscle contraction speed. Regardless of the elongation model used, the quadriceps dominate the muscle group during a slow contraction (60°/s), while the hamstrings play a much larger role at high speeds. Findings from Andrade et al. (2012), who pointed out that differences in training methods could affect the strength ratios across different sports, including handball, further support the connection between strength training and the hamstring quadriceps ratio. According to their research, male and female athletes have different HQR which may call for training methods tailored to each gender in order to maximize performance and lower the risk of injury. Furthermore, numerous studies have shown the predictive effectiveness of the hamstring quadriceps ratio (HQR) to predict injury risk. A low HQR is a major risk factor for hamstring injuries, according to Dauty et al. (2018), who also recommended that in order to identify possible inadequacies, regular isokinetic assessments be included in athlete monitoring programs.

The aim of our study is to assess the strength of hamstring and quadriceps muscles in professional handball players using isokinetic diagnostics, which is regarded as the most reliable measuring method.

2. METHODS

2.1. Design and Participants

This study used a cross-sectional design and included 8 male professional handball players of RK "Borac M:tel" from Banja Luka, member Premier League BIH, with the following average characteristics: Body height 193.26±4.39cm; Body weight 93.50±10.25kg; BMI 24.49±1.34kg/m²; Age=26.38±5.70.

The criteria for inclusion were: (1) that the age of the handball player is at least 16 years (±6 months), (2) that all handball players included in the sample are registered for their club, with a license to participate in the competition within the regular period, (3) without injuries in the last six months, (4) that they actively train handball for at least 3 to 6 years, (5) that all handball players have five training sessions per week, (6) that the training sessions last 90-120 minutes, (7) that the respondents are included in the team composition, including substitutes, (8) that they have a favorable health status.

The group was very homogeneous in terms of anthropometric characteristics and motoric abilities. The participants have been familiarized with the measuring protocol and they signed

consent of voluntary accession to the test. The study was performed in accordance with the Declaration of Helsinki and was approved by the Ethics Board of Faculty of physical education and sport. The subjects were informed of the benefits and risks of the investigation prior to signing an institutionally approved informed consent document to participate in the study. The participants underwent isokinetic testing using a computerized dynamometer. They performed flexion and extension movements at different velocity, first in the form of slow, then fast contraction.

2.2. Sample Variables

The following variables were taken into account from the anthropological measures: Body height – BH (cm); Body weight – BW (kg); Body mass index – BMI (kg/m²); Chronological age – AGE (year); Playing years.

In operational terms, the following variables were monitored for the right (R) and left (L) leg: Maximum quadriceps torque – MQT (Nm/kg); Maximum hamstring torque – MHT (Nm/kg); Hamstring quadriceps ratio - HQR (Nm/kg).

Body weight (BW) and body mass index (BMI) were measured using bioelectrical impedance on a customized Tanita BC418a scale (USA) with an accuracy of 0.1kg, and body height (BH) was measured using a Seca 216 (GER) altimeter with an accuracy of 0.5cm.

Isokinetic muscle strength testing was performed up at the Institute of Sports, Faculty of Physical Education and Sports, University of Banja Luka. Isokinetic testing was conducted using isokinetic multi joint module dynamometer CON-TREX® MJ (Switzerland) which allows for precise diagnostics and subject-specific results. Note: During testing, gravity was not taken into account.

2.3. Measurement Protocol

The testing was done between 09.00 and 12.00 hours, in the Institute of the Faculty and in air-conditioned conditions where the temperature was maintained between 22℃ - 24℃. The procedure required the presence of one parameter measurer and an expert trained to handle the device. Testing was performed for the concentric mode of quadriceps and hamstring contraction, in the range of motion from 0° to 90° flexion, at a speed of 60°/sec. The research was conducted on both legs. On the day of the test, the handball player did not train, and the test was conducted in accordance with the usual methodology for such tests. Prior to the test, the isokinetic equipment was calibrated. The respondent-handball player has knowledge of the testing process, which states (Gerdijan et al., 2011): The seat of the device was modified to position the handball player in the proper posture, assuring his

stability on the isokinetic chair. Seat limitations were used to immobilize the handball player and isolate the tested musculature to the greatest extent possible.

After identifying the proper position on the chair (hips at a 60° angle), the anatomical axis of the knee must be aligned with the dynamometer's axis. The axis of rotation on the dynamometer was aligned with the handball player's knee and set to a range of motion from 0° to 90°. When measuring the knee, the reference point is the external femoral condyle. Testing began with an adequate warm-up of the handball player (they performed three submaximal contractions with the flexors and extensors of the upper leg. After that, they warmed up at speeds of 60° and 120°/s).

After a 30-second break, they performed one trial test at a speed of 60°/s, with three repetitions, after which the testing procedure began. During the test, 4 maximal contractions were performed, first with the front and then with the back muscle group, without alternation. The identical procedure was performed first with one leg, then with the other, with an active rest between procedures lasting 60 seconds. Testing of the knee muscle strength was performed at a constant speed of movement of 60º/s (testing of maximal muscle strength). The highest torque recorded was taken for analysis.

2.4. Statistical Analyses

The arithmetic mean (Mean) and standard deviation (SD) were calculated for each variable. For further statistical analysis, a comparative approach was applied, specifically testing the significance of differences between the means of independent samples using the T-test, which falls within the domain of discriminative procedures. Data processing and reporting were performed using the statistical software IBM SPSS, Version 20. All conclusions were drawn at a significance level of 0.05 ($p < 0.05$). The results of the statistical analyses are presented in tabular form.

3. RESULTS

The sample of handball players had a mean body weight (BW) of 93.5±10.25kg, with the lowest BW being 83kg and the highest being 114 kg, according to the results of the fundamental anthropological parameters (Table 1). Body height (BH) ranged from a minimum of 187.00 cm to a maximum of 200.00 cm. The sample's average height was Mean=193.25±4.39cm. The average computed body mass index (BMI) was 24.49 kg/m², with a range of 22.10 to 26.80 kg/m². The examined sample's body mass index result was between the recommended body mass range of 20.00 and 24.99. They classified the studied sample of handball players as exceptionally homogeneous as

the coefficient of variation (CV%.) values for the observed variables of the anthropological space do not surpass 0.2 (Perić, 2001).

Table 1. Basic anthropological parameters of the sample

Variables	N	Min.	Max.	Mean	SD	CV
BW (kg)	8	83.00	114.00	93.50	10.253	0.109
BH (cm)	8	187.00	200.00	193.25	4.399	0.022
BMI (kg/m²)	8	22.10	26.80	24.49	1.342	0.054
Age (years)	8	19.00	35.00	26.38	5.705	0.216
Playing years	8	3.00	15.00	7.50	4.407	0.587

Note. *Legend: N – number of respondents; BH- body height; BW - body weight; BMI - body mass index; Mean - arithmetic mean; SD. - standard deviation; St.Error - standard error of the arithmetic mean; CV - coefficient of variation.*

The bilateral relationship between the strength of the right and left legs in handball players at the *Maximum quadriceps torque (MQT)* is displayed in Table 2 together with the basic statistical data. Mean=2.45±0.411 is the average quadriceps strength for the right leg, while Mean=2.72±0.522 is the average quadriceps strength for the left leg.

Table 2. Descriptive statistics for the variable maximum quadriceps torque (MQT) – bilateral relationship

Group Statistics				
	Leg	Mean	SD	Std. Error
MQT (Nm/kg)	Right	2.452	0.411	0.145
	Left	2.721	0.522	0.185

In handball players, the arithmetic means of the quadriceps strength of the right and left legs differ numerically. To determine whether the obtained values were statistically significant, the significance of the differences of the arithmetic means for the variable *Maximum quadriceps torque (MQT)* was examined in Table 3.

The table shows the following: Levene's test result for the variable *Maximum quadriceps torque (MQT)* indicates a significance value of Sig.=0.365, which is greater than 0.05, for examining the homogeneity (equality) of variances in the t-test. This indicates acceptance of the equality of variance assumption. For df=14, the computed t-value from the domain of testing the equivalence of arithmetic means is t = -1.143. It can be inferred that the differences are not statistically significant because the obtained t value is less than the cutoff (t<2.145). At the same time, the two-way t-test's

Sig. (2-tailed) level of significance was 0.272. The conclusion is that there is no statistically significant difference in the way the quadriceps of the right and left legs show strength when assessing the *Maximum quadriceps torque (MQT)* on a bilateral basis.

Table 3. Independent samples t-test for the variable maximum quadriceps torque (MQT)

		Levene's Test for Equality of ariances		**T-test for Equality of Means**				
		F	Sig.	T	df	p	Mean Diff.	Std. Error Diff.
MQT	Equal var. assumed	0.877	0.365	-1.143	14	0.272	-0.269	0.235
	Equal var. not assumed			-1.143	13.274	0.272	-0.269	0.235

Note. *Legend: df – number of degrees of freedom; F value – null hypothesis testing; Sig. – realized level of significance; p – probability value; t – the value of the arithmetic means difference test; Mean - arithmetic means for both samples; St. Dev. - standard deviations for both samples; St. Error - ratings of standard errors of the arithmetic mean. df=14; p=0.05; limit value t =2.145;*

The bilateral relationship between a handball player's right and left legs at *Maximum hamstring torque (MHT)* is displayed in Table 4. Arithmetic mean values (Means) for the right and left legs are, respectively, Mean =1.559±0.183 and Mean =1.557±0.338.

Table 4. Descriptive statistics for the variable maximum hamstring torque (MHT) – bilateral relationship

Group Statistics				
	Leg	Mean	SD	Std. Error
MTH (Nm/kg)	Right	1.559	0.183	0.065
	Left	1.557	0.338	0.120

For the variable *Maximum hamstring torque (MHT)*, the importance of the variations in arithmetic means is examined in Table 5. The following is displayed in the table: The Levene test result for the variable *MHT* shows a significance value Sig.=0.077, which is greater than 0.05, for examining the homogeneity (equality) of variances inside the t-test. This indicates acceptance of the equality of variance assumption. For df=14, the computed t-value from the domain of testing the equivalence of arithmetic means is t=0.018. It is determined that the differences are not statistically significant because the obtained t value is below the threshold (t<2.145).

Table 5. Independent samples t-test for the variable maximum hamstring torque (MHT**)**

		Levene's Test for Equality of Variances		**T-test for Equality of Means**				
		F	Sig.	T	df	p	Mean Diff.	Std. Error Diff.
MHT	Equal var. assumed	3.636	0.077	0.018	14	0.986	0.002	0.136
	Equal var. not assumed			0.018	10.784	0.986	0.002	0.136

The unilateral ratio of the right and left leg in handball players at the maximum torque of the hamstring and quadriceps muscle groups *(Hamstring quadriceps ratio)* is displayed in Table 6. The arithmetic mean (Mean) for the right leg is 64,300±8,065; the arithmetic mean for the left leg is 58,937±15,036.

Table 6. Descriptive statistics for variable hamstring quadriceps ratio (HQR) - unilateral relationship

Group Statistics				
	Leg	Mean	SD	Std. Error
HQR (%)	Right	64.300	8.065	2.851
	Left	58.937	15.036	5.316

For the variable *Hamstring quadriceps ratio (HQR),* the significance of the variations in arithmetic means was examined in Table 7. The following is displayed in the table: The Levene test result for the variable *HQR* indicates the significance value Sig.=0.431, which is greater than 0.05, for assessing the homogeneity (equality) of variances inside the t-test. This indicates acceptance of the equality of variance assumption.

For df=14, the computed t-value from the domain of testing the equivalence of arithmetic means is t =0.889. It can be inferred that the differences are not statistically significant because the obtained t value is less than the cutoff (T<2.145).

The two-way t-test's Sig. (2-tailed) level of significance is 0.389. Given that the realized level of significance (Sig.>0.05) is higher than 0.05. We may conclude that there is no statistically significant difference when comparing the unilateral level of the *Hamstring quadriceps ratio*. According to the results of the *Hamstring quadriceps ratio,* the right leg's ratio is 64.3%, while the left leg's is 58.9%.

Table 7. Independent samples t- test for the variable hamstring quadriceps ratio (HQR)

		Levene's Test for Equality of Variances		T-test for Equality of Means				
		F	Sig.	T	Df	p	Mean Diff.	Std. Error Diff.
HQR	Equal var. assumed	0.656	0.431	0.889	14	0.389	5.362	6.032
	Equal var. not assumed			0.889	10.720	0.394	5.362	6.032

4. DISCUSSION

Muscular strength and power are important in terms of basic physiological capacities in handball game. During handball matches, players perform a large number of different jumps, hand strikes, falls to the ground, quick turns and various technical exercises that characterize the dynamics of the game by constantly changing places, or positions on the court. Therefore, the relationship between torque and speed and the strength of the lower limb muscles of athletes is particularly important during a handball game. In general, in all sports games, the quadriceps and knee muscles are integrated into motor skills (running, jumping), and muscle strength is one of the most important components of these sports, both for high performance and for injury prevention (Askling et al., 2003). Injuries to these muscle groups are one of the main problems faced by today's athletes, including handball players.

The purpose of this study is to evaluate the strength of the left and right hamstring and the quadriceps muscle group in professional handball players. It also aims to assess the statistical significance of the relationship between these two muscle groups.

According to the findings, there is little variation in the strength of the left and right quadriceps and hamstrings among handball players, and no bilateral or unilateral muscle imbalance was observed. At the group level, the left leg had higher maximum quadriceps torque than the right leg (left -2.72, right leg- 2.45 Nm/kg). Hamstring values were equal bilaterally. The Hamstring quadriceps ratio findings show that the right leg is 64.3% and the left leg is 58.9%. Even though there was no statistically significant difference, this indicates that the left leg's hamstrings are weak by over 10% when compared to the expected values. Gerdijan et al. (2021) suggest that high imbalance values in specific muscle groups increase the risk of muscle injury.

Gonzales-Riva et al. (2014) reported similar findings, recording seated data from 12 senior Spanish league handball players: the isokinetic quadriceps strength of the dominant leg was 2.91

Nm/kg, whereas that of the non-dominant leg was 2.70 Nm/kg. The dominant leg's hamstring strength was 1.76, while the non-dominant leg's measures 1.72 Nm/kg.

A large amount of research seems to agree that sports-specific demands have an impact on the hamstring quadriceps ratio (Andrade, 2012; Ruas et al., 2015) and that increasing the hamstring quadriceps ratio (HQR) is a good way to reduce the risk of injury in rotating sports (Orchard et al., 1997; Kukrić et al., 2021). There is ongoing controversy regarding the true meaning of these HQR nevertheless, as other studies have found no impact of increasing the ratio on injury risk (Steffen et al., 2017). According to Dauty et al. (2017), a low HQR is a significant risk factor for hamstring injuries. They also suggested that regular isokinetic tests be incorporated in athlete monitoring programs to identify potential deficiencies.

In conclusion, this study's findings could help clarify a number of crucial anthropometric and physical elements of handball play. In addition to demonstrating that professional handball players are symmetrical and have no notable maximal strength deficiencies between and within the knee extensors and flexors, new data about the maximum torque of the quadriceps (extensors) and hamstrings (flexors) were presented.

There are several limitations to this study. The small number of participants causes sensitivity when interpreting results, emphasizing the necessity for more subjects in future research. This study presents preliminary isokinetic strength data for the quadriceps and hamstring muscles used by professional handball players.

5. CONCLUSIONS

According to the findings, there is little variation in the strength of the left and right quadriceps and hamstrings among handball players, and no bilateral or unilateral muscle imbalance was observed. For professional and elite sports, the information from isokinetic diagnostics is very important for planning the training program and preventing injuries. This study provides normative data for the handball player population.

6. REFERENCES

1. Åman, M,, Forssblad, M., & Larsén, K. (2018). Incidence and body location of reported acute sport injuries in seven sports using a national insurance database. *Scandinavian Journal of Medicine & Science in Sports*, 28(3), 1147-1158. https://doi.org/10.1111/sms.12956.
2. Åman, M., Forssblad, M., & Larsén, K. (2019). National injury prevention measures in team sports should focus on knee, head, and severe upper limb injuries. *Knee Surgery, Sports Traumatology, Arthroscopy, 27*(3), 1000-1008. https://doi.otg/10.1007/s00167-018-5225-7

3. Andrade, M. S., Lira, D., Koffes, C. A., Mascarin, F. C., Benedito-Silva, N. C., & Silva, D. (2012). Isokinetic hamstrings-to-quadriceps peak torque ratio: The influence of sport modality, gender, and angular velocity. *Journal of Sports Sciences, 30*, 547–553.
4. Asai, K., Nakase, J., Shimozaki, K., Toyooka, K., Kitaoka, K., & Tsuchiya, H. (2020). Incidence of injury in young handball players during national competition: A 6-year survey. *Journal of Orthopaedic Science, 25*(4), 677-681. https://doi.org/10.1016/j.jos.2019.06.011.
5. Askling, C., Karlsson, J., & Thorstensson, A. (2003). Hamstring injury occurrence in elite soccer players after preseason strength training with eccentric overload. *Scandinavian Journal of Medicine & Science in Sports*, *13*(4), 244–250. https://doi.org/10.1034/j.1600-0838.2003.00312.x
6. Bere, T., Alonso, J., Wangensteen, A., Bakken, A., Eirale, C., Dijkstra, H. P., Ahmed, H., Bahr, R., & Popović, N.(2015). Injury and illness surveillance during the 24th Men's Handball World Championship 2015 in Qatar. *British Journal of Sports Medicine, 49,* 1151-1156. http://dx.doi.org/10.1136/bjsports-2015-094972.
7. Chaouachi, A., Brughelli, M., Levin, G., Boudhina, N. B., Cronin, J., & Chamari, K. (2009). Anthropometric, physiological and performance characteristics of elite team-handball players. *Journal of Sports Sciences*, *27*(2), 151–157. https://doi.org/10.1080/02640410802448731
8. Chen, C. H., Chiu, C. H., Tseng, W. C., Wu, C. Y., Su, H. H., Chang, C. K., & Ye, X. (2023). Acute Effects of Combining Dynamic Stretching and Vibration Foam Rolling Warm-up on Lower-Limb Muscle Performance and Functions in Female Handball Players. *Journal of Strength and Conditioning Research*, *37*(6), 1277–1283. https://doi.org/10.1519/JSC.0000000000003998
9. Clarsen, B., Bahr, R., Heymans, M. W., Engedahl, M., Midtsundstad, G., Rosenlund, L., Thorsen, G., & Myklebust, G. (2015). The prevalence and impact of overuse injuries in five Norwegian sports: Application of a new surveillance method. *Scandinavian Journal of Medicine & Science in Sports*, *25*(3), 323–330. https://doi.org/10.1111/sms.12223
10. Dauty, M., Menu, P., & Fouasson-Chailloux, A. (2018). Cutoffs of isokinetic strength ratio and hamstring strain prediction in professional soccer players. *Scandinavian Journal of Medicine & Science in Sports*, *28*(1), 276–281. https://doi.org/10.1111/sms.12890
11. Florit, D., Pedret, C., Casals, M., Malliaras, P., Sugimoto, D., & Rodas, G. (2019). Incidence of Tendinopathy in Team Sports in a Multidisciplinary Sports Club Over 8 Seasons. *Journal of Sports Science & Medicine*, *18*(4), 780–788.
12. Gerdijan, N., Perić, D., & Kazazović, E. (2017). The acute effect of stretching on force and power. *Homo Sporticus, 19*, 5-11.
13. Gerdijan, N., Perić, D., Ljubojević, A., & Vukić, Ž. (2021) Effects of Static and Dynamic Stretching Exercises on Unilateral Hamstring to Quadriceps Strength Ratio. *Advances in Physical Education, 11*, 89-102.
14. Gerdijan, N., Zeljković, M., Lukić, A., & Vukić, Ž. (2011). Unilateral and bilateral relationship of upper leg muscles in tennis players. In S. Simović (Ed.), *II International Congress: Anthropological aspects of sport, physical education and recreation* (pp. 200–206). Banja Luka.
15. González-Ravé, J. M., Juárez, D., Rubio-Arias, J. A., Clemente-Suarez, V. J., Martinez-Valencia, M. A., & Abian-Vicen, J. (2014). Isokinetic leg strength and power in elite handball players. *Journal of Human Kinetics, 41*, 227–233. https://doi.org/10.2478/hukin-2014-0050
16. 19. Kukrić, A., Joksimović, M., Petrović, B., Latino, F., Pavlović, R., & Kuvalja, R. (2021). Ratio of maximum hamstring torque to maximum quadriceps torque in professional basketball and soccer players. *Health, Sport, Rehabilitation*, *7*(4), 8–18. https://doi.org/10.34142/HSR.2021.07.04.01
17. Haugen, T. A., Tønnessen, E., & Seiler, S. (2016). Physical and physiological characteristics of male handball players: influence of playing position and competitive level. *The Journal of Sports Medicine and Physical Fitness*, *56*(1-2), 19–26.

18. Hermassi, S., Chelly, M. S., Wagner, H., Fieseler, G., Schulze, S., Delank, K. S., Shephard, R. J., & Schwesig, R. (2019). Relationships between maximal strength of lower limb, anthropometric characteristics and fundamental explosive performance in handball players. Zusammenhänge zwischen der Maximalkraft der unteren Extremitäten, anthropometrischen Eigenschaften und der grundlegenden Explosivkraft bei Handballspielern. *Sportverletzung Sportschaden: Organ der Gesellschaft fur Orthopadisch-Traumatologische Sportmedizin*, *33*(2), 96–103. https://doi.org/10.1055/s-0043-124496
19. Luig, P., & Henke, T. (2011). [Title of chapter if available]. In F. Taborsky (Ed.), *Science and analytical expertise in handball: Scientific and practical approaches* (pp. 78–83). European Handball Federation.
20. Luig, P., Krutsch, W., Henke, T., Klein, C., Bloch, H., Platen, P., & Achenbach, L. (2020). Contact - but not foul play - dominates injury mechanisms in men's professional handball: a video match analysis of 580 injuries. *British Journal of Sports Medicine*, *54*(16), 984–990. https://doi.org/10.1136/bjsports-2018-100250
21. Lund-Hanssen, H., Gannon, J., Engebretsen, L., Holen, K., & Hammer, S. (1996). Isokinetic muscle performance in healthy female handball players and players with a unilateral anterior cruciate ligament reconstruction. *Scandinavian Journal of Medicine & Science in Sports*, *6*(3), 172–175. https://doi.org/10.1111/j.1600-0838.1996.tb00085.x
22. Mashimo, S., Yoshida, N., Moriwaki, T., Takegami, A., Suzuki, K., Fong, D. T. P., Myklebust, G., & Onishi, S. (2021). Injuries in Japanese university handball: a study among 1017 players. *Research in Sports Medicine (Print)*, *29*(5), 475–485. https://doi.org/10.1080/15438627.2021.1937164
23. Maurelli, O., Bernard, P. L., Dubois, R., Ahmaidi, S., & Prioux, J. (2019). Effects of the Competitive Season on the Isokinetic Muscle Parameters Changes in World-Class Handball Players. *Journal of Strength and Conditioning Research*, *33*(10), 2778–2787. https://doi.org/10.1519/JSC.0000000000002590
24. Orchard, J., Marsden, J., Lord, S., & Garlick, D. (1997). Preseason hamstring muscle weakness associated with hamstring muscle injury in Australian footballers. *The American Journal of Sports Medicine*, *25*(1), 81–85. https://doi.org/10.1177/036354659702500116
25. Orchard, J., Marsden, J., Lord, S., & Garlick, D. (1997). Preseason hamstring muscle weakness associated with hamstring muscle injury in Australian footballers. *The American Journal of Sports Medicine*, *25*(1), 81–85. https://doi.org/10.1177/036354659702500116
26. Ortega-Becerra, M., Pareja-Blanco, F., Jiménez-Reyes, P., Cuadrado-Peñafiel, V., & González-Badillo, J. J. (2018). Determinant Factors of Physical Performance and Specific Throwing in Handball Players of Different Ages. *Journal of Strength and Conditioning Research*, *32*(6), 1778–1786. https://doi.org/10.1519/JSC.0000000000002050
27. Palmer, D., Cooper, D. J., Emery, C., Batt, M. E., Engebretsen, L., Scammell, B. E., Schamasch, P., Shroff, M., Soligard, T., Steffen, K., Whittaker, J. L., & Budgett, R. (2021). Self-reported sports injuries and later-life health status in 3357 retired Olympians from 131 countries: a cross-sectional survey among those competing in the games between London 1948 and PyeongChang 2018. *British Journal of Sports Medicine*, *55*(1), 46–53. https://doi.org/10.1136/bjsports-2019-101772
28. Perić, D. (2001). *Statistics - application to sports and physical education.* Belgrade: Faculty of Physical Education.
29. Rafnsson, E. T., Valdimarsson, Ö., Sveinsson, T., & Árnason, Á. (2019). Injury Pattern in Icelandic Elite Male Handball Players. *Clinical Journal of Sport Medicine*, *29*(3), 232–237. https://doi.org/10.1097/JSM.0000000000000499

30. Ruas, C. V., Minozzo, F., Pinto, M. D., Brown, L. E., & Pinto, R. S. (2015). Lower-extremity strength ratios of professional soccer players according to field position. *Journal of Strength and Conditioning Research*, *29*(5), 1220–1226. https://doi.org/10.1519/JSC.0000000000000766
31. Shelton, J. & Kumar, G. (2009) Comparison between static and dynamic warm-up exercise regimes on lower limb muscle power. *Health, 1,* 117-120.
32. Steffen, K., Nilstad, A., Krosshaug, T., Pasanen, K., Killingmo, A., & Bahr, R. (2017). No association between static and dynamic postural control and ACL injury risk among female elite handball and football players: a prospective study of 838 players. *British Journal of Sports Medicine*, *51*(4), 253–259. https://doi.org/10.1136/bjsports-2016-097068
33. Tabben, M., Landreau, P., Chamari, K., Juin, G., Ahmed, H., Farooq, A., Bahr, R., & Popovic, N. (2019). Age, player position and 2 min suspensions were associated with match injuries during the 2017 Men's Handball World Championship (France). *British Journal of Sports Medicine*, *53*(7), 436–441. https://doi.org/10.1136/bjsports-2018-099350
34. Teixeira, J., Carvalho, P., Moreira, C., & Santos, R. (2014). Isokinetic assessment of muscle imbalances and bilateral differences between knee extensores and flexores' strength in basketball, footbal, handball and volleyball athletes. *International Journal of Sports Science, 4,* 1–6.
35. Vila, H., Barreiro, A., Ayán, C., Antúnez, A., & Ferragut, C. (2022). The Most Common Handball Injuries: A Systematic Review. *International Journal of Environmental Research and Public Health*, *19*(17), 1-17. https://doi.org/10.3390/ijerph191710688
36. Xaverova, Z., Dirnberger, J., Lehnert, M., Belka, J., Wagner, H., & Orechovska, K. (2015). Isokinetic Strength Profile of Elite Female Handball Players. *Journal of Human Kinetics*, *49*, 257–266. https://doi.org/10.1515/hukin-2015-0128

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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