ORIGINAL SCIENTIFIC PAPER

Isokinetic profiles of hamstring and quadriceps muscles in the police special force operators

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Abstract

Knee injuries are of concern to police. The aims of this study were to determine initial reference values for isokinetic knee extension and flexion in police special force operators to explore the conventional hamstring contraction (Hcon) quadriceps contraction (Qcon) ratio, and to determine the limb symmetry index of the quadriceps and hamstring muscles. Absolute and relative isokinetic torque of quadriceps and hamstrings were assessed in 10 police special force operators using an isokinetic dynamometer Con-Trex. Subjects performed maximal knee extension and flexion at a contraction velocity of 60°/s at 90° of knee flexion. Means, standard deviations, 95% confidence interval values, and effect sizes were calculated. A paired samples t-test was used to test the between-leg differences in absolute and relative torques of quadriceps and hamstring muscles and to test the between-leg difference in Hcon/Qcon ratios as well as strength asymmetries of quadriceps and hamstrings. Descriptive statistics revealed torque values similar to athletes, and paired sample t-tests showed no significant between-leg differences in torque values at a group level. Small effect sizes were observed between legs in both the absolute and relative peak torque of the hamstring muscles. While, on a group level, no Hcon/Qcon ratio disparity between legs or asymmetries were observed, individual results indicated a trend towards greater dispersion for the dominant leg and some individual results indicated an increased asymmetry in isometric strength of hamstrings. The study provides normative data for this unique police population and highlights the need for relative strength work in this population.

Keywords: *knee function, injury prevention, muscle strength, leg extension*

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ISOKINETIC STRENGTH IN POLICE SPECIAL FORCE OPERATORS
http://mjssm.me/?sekcija=article&artid=270

Cite this article: Kukrić, A., Zlojutro, N., Orr, R., Joksimović, M., Kukić, F. (2024) Isokinetic profiles of hamstring and quadriceps muscles in the police special force operators. *Montenegrin Journal of Sports Science and Medicine,* 20 (1), Ahead of print. https://doi.org/10.26773/mjssm.240305

Introduction

Considering the structure, function, and daily workload of the knee joint, injuries to this structure are common for many population groups and occur regardless of gender, age, or type of physical activity being performed (Gage et al., 2012). This is also true for physically demanding occupations such as tactical professions, inclusive of police forces (Lyons et al., 2021). As examples, a large retrospective cohort study of 12,452 lower limb injuries suffered by police officers found that the knee was the most common site of injury (31% of all lower limb injuries) (Lyons et al., 2021) whilst in general duties officers in particular, the knee was been identified as the leading site of

Received: 16 November 2023 | Accepted after revision: 15 February 2023 | Early access publication date: 01 March 2024 | Final publication date: 15 March 2024

Conflict of interest: None declared.

injury overall (Orr et al., 2023). Of concern, research suggests that, together with firefighters, police officers have more days away from work following a knee injury than other US government workers (Chen et al., 2013). Thus, not only are knee injuries common but they have a notable impact on police officers and their agencies.

Knee injury frequency and their impacts are not surprising given the nature of the law enforcement profession. Police officers respond to a variety of tasks from checking a suspicious person's credentials to attending a domestic dispute and arresting offenders (Orr, Hinton, et al., 2020) all while wearing around 10 kg of personal protective equipment on their bodies (Baran et al., 2018). Thus, officers' tasks can range from general duties deskwork and driving in vehicles, to chasing offenders on foot across various terrains and over obstacles. One means of mitigating injury in police personnel is through physical fitness whereby personnel with higher levels of fitness are generally at a lower risk of injury (Orr et al., 2023) with physical fitness associated with many policing tasks (Lockie et al., 2023). As such, physical fitness is considered a very important pillar of policing (Orr, Robinson, et al., 2022). Noting this requirement for general duties officers, specialist police perform tasks beyond those of general duties police officers, carry loads of 20+ kg, and are required to be fitter than general duties officers (Maupin et al., 2018).

Although various tests are applied in practice to assess risk of the injury (Orr, Lockie, et al., 2022), the isokinetic tests for the strength imbalance index between muscle groups surrounding the knee joint (i.e., hamstring contraction to quadriceps contraction ratio, Hcon/Qcon ratio) is among the few precise measures available (Coombs & Garbutt, 2002). The conventional Hcon/Qcon ratio represents the ratio between the peak torque of the hamstring and the quadriceps muscles and is measured during concentric contractions (Pellicer-Chenoll et al., 2017). Hewett et al. (2008) found a correlation between the conventional Hcon/Qcon ratio and angular velocity of movement in non-athletes, where an increase in angular velocity led to an increase in the Hcon/Qcon ratio. Furthermore, studies have found that low values of a Hcon/Qcon ratio (e.g., Hcon/Qcon < 0.60 at an angular velocity of 60°/sec) increased the risk of knee joint (e.g. anterior cruciate ligament tear) and supporting structure (e.g., hamstring strain) injuries (Coombs & Garbutt, 2002). Thus, diagnosing the Hcon/Qcon ratio could provide an early indication of increased risk of injury to the knee joint and supporting structures.

Analyzing the risk of injury in police officers using standardized laboratory conditions and equipment, such as isokinetic testing, is scarce. Rare opportunities, when the utilization of such tests is possible, should be used to build the scientific body of knowledge and possibility of developing standards for an individual assessment of officer's knee joint injury risk. Considering this, the aim of this study was to determine reference values for isokinetic knee extension (quadriceps muscle) and flexion (hamstring muscle) in specialist police forces. Furthermore, the study aimed to explore the conventional Hcon/Qcon ratio and to determine the limb symmetry index (LSI) in quadriceps and hamstring muscles in this population. At an individual officer level, this information can inform their conditioning, and reconditioning following knee injury, requirements.

Methods

Experimental approach to the problem

This study employed a cross-sectional research design on a specific sample of subjects who served as specialist police officers. The research was conducted at the Faculty of Physical Education and Sports, University of Banja Luka, Bosnia and Herzegovina. Subjects visited the laboratory once. During their visit their anthropometric characteristics were taken following which they warmed up, performed a familiarization trial, and then performed the test of hamstring and quadriceps muscle isokinetic strength. The research was approved by the Ethics Committee of the Faculty of Physical Education and Sports, University of Banja Luka. The research was conducted in accordance with the Helsinki Declaration.

Subjects

Subjects were 10 male (mean age = 26 ± 4.89 years; mean height = 179.90 ± 4.74 cm, mean mass = 89.10 ± 6.33 kg; and mean body mass index (BMI) = 27.5 ± 2.21 kg/m2) members of the special police units of the Republic of Srpska, Bosnia and Herzegovina. All subjects were experienced police officers with a minimum of 3 years of service in the police force. They were all physically active, engaging in at least three weekly organized conditioning training sessions. They were in good physical and mental health, without lower body injuries that could influence the research results, and regularly participated in organized physical activities within their units. Subjects were informed about the purpose and objectives of the research and the measurement protocols, and all voluntarily agreed to participate in the study.

Anthropometrics

Subject body mass was measured using a Tanita BC418a scale (USA) with a precision of 0.1 kg. Body height was measured using a Seca 216 stadiometer (Germany) with an accuracy of 0.5 cm. Of the 10 subjects, 8 reported that they were right leg dominant, with the remaining 2 reporting their left leg to be dominant. No subjects reported being ambipedal.

Quadriceps and hamstring torque

A general warm-up was performed on a stationary bicycle (Monark, Cosmed, Italy). Subjects cycled for 8 minutes and then performed a dynamic warm-up of the lower limbs for 3 min, and dynamic stretching for 2 min. This warm up was self-directed by each subject under the observation and direction of a researcher. The isokinetic test was performed on an isokinetic dynamometer (Con-Trex, Dubendorf, Switzerland). Subjects were seated, with the upper/lower body angle at approximately 85°. Subjects were fully secured with straps over the chest, hips, and distal thighs. The reference point for the axis of rotation was the lateral femoral condyle. The lever arm length was individually determined for each subject, and the range of motion was 90° of knee flexion, whereby 0° corresponded to extended knee (Norkin & White, 2016). The testing protocol on the isokinetic dynamometer involved performing two sets of warm-ups and adaptation for subjects on the machine. In the first set, subjects performed 10 submaximal concentric contractions of flexor and extensor muscles in the knee joint at an angular velocity of 100°/s. After a two-minute break, subjects performed 8 submaximal contractions at an angular velocity of 80°/s. After another at least two-minute rest, subjects proceeded to the final measurement, where they performed four maximal repetitions at an angular velocity of 60°/s. The rest between legs was at least five minutes.

DOI 10.26773/mjssm.240305

Statistical analysis

For analysis, the absolute and relative peak torque values of hamstring and quadriceps muscles were used. The absolute results are presented in newton-meter (N/m) and the relative results in newton-meter per kilogram (Nm/kg). The conventional Hcon/Qcon ratio of concentric contraction was determined by dividing the peak torque of hamstring muscles by the peak torque of quadriceps muscles. The LSI was calculated to determine the percentage of the difference in peak torque produced by the same muscle group of dominant and non-dominant leg. The following formula was used to determine LSI: (peak torque of dominant leg – peak torque of non-dominant leg) / peak torque of dominant leg × 100. The size of the of the asymmetry was determined using a general normative value of 15% and using group arbitrary values of ±2 standard deviations (Parkinson et al., 2021).

The testing results were analyzed using JASP (version 0.18.1, Amsterdam). The descriptive analysis determined the mean, standard deviation, and 95% confidence interval for all investigated variables. The normality of distribution was tested using the Shapiro-Wilk test and all variables were normally distributed. Accordingly, parametric statistical tests were used. A paired samples t-test was used to investigate the between-leg differences in absolute and relative torque of quadriceps and hamstring muscles. This test was also used to test the between-leg difference in Hcon/Qcon ratios. Cohen's effect size (d) was used to quantify the differences as d < 0.2 (trivial or no effect), d = 0.2–0.5 (small), d = 0.5–0.8 (moderate), d = 0.8–1.3 (large), or d >1.3 (very large) (Sullivan & Feinn, 2012). As the study employed a sample of convenience, Power*G software was used to determine the required power for the given sample and level of significance and based on this analysis 0.5 was used as the lower bound for a small effect size.

Results

Table 1 presents the mean, standard deviation, and 95% confidence interval of absolute and relative peak torque values for quadriceps and hamstring muscles for both dominant and non-dominant legs. There were no significant between-leg differences in absolute and relative torque obtained by quadriceps and hamstrings muscles. However, observing the distribution of subjects and consulting the effect size analysis (Figure 1), the difference of a small effect size could be observed between legs in both the absolute (TmaxHams) and relative (TrelHams) peak torque of the hamstring muscles.

Table 1. Means, standard deviations, and effect sizes for absolute and relative peak torque values of flexor and extensor in the knee joint dominant and non-dominant leg.

Variables	Dominant leg	Non-dominant leg	Effect sizes
	Mean ± SD 95% Conf. Interval	Mean ± SD 95% Conf. Interval	
TmaxQuad (Nm)	228.45 ± 15.83 217.13–239.77	228.66 ± 24.53 211.11–246.21	Trivial
TmaxHams (Nm)	142.09 ± 26.40 123.21–160.97	134.14 ± 25.13 116.16–152.12	Small
TrelQuad (Nm/kg)	2.57 ± 0.17 2.45–2.70	2.57 ± 0.27 2.38–2.77	Trivial
TrelHams (Nm/kg)	1.59 ± 0.25 1.41–1.78	1.51 ± 0.26 1.32–1.69	Small

Note. SD: standard deviation; TmaxQuad: absolute peak torque of quadriceps muscles; TmaxHams: absolute peak torque of hamstring muscles; TrelQuad: relative peak torque of quadriceps muscles; TrelHams: relative peak torque of hamstring muscles.

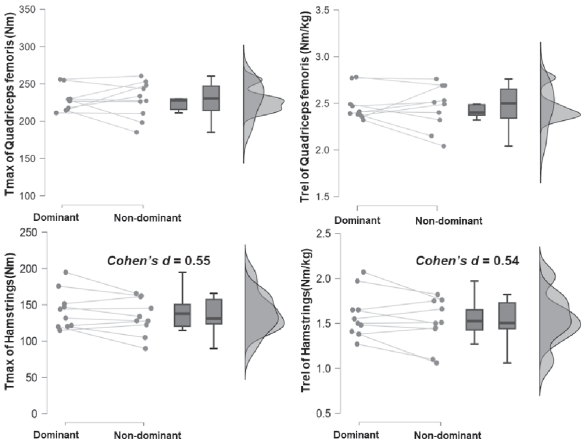

Figure 1. The distribution of absolute and relative torque exerted by Quadriceps and Hamstrings muscles.

Hcon/Qcon ratio

The mean values of the Hcon/Qcon ratio were similar within dominant (Hcon/Qcon = 0.61 ± 0.11) and non-dominant (Hcon/Qcon = 0.58 ± 0.08) legs. In addition, there were no significant between-leg differences in Hcon/Qcon ratios (p = 0.19). However, a tendency towards a greater dispersion of absolute Hcon/Qcon ratio could be observed in the dominant leg when compared to the non-dominant leg. It is of note that two subjects had high relative Hcon/Qcon in their dominant leg and that the dispersion of between-leg differences were bigger when the Hcon/Qcon of the dominant leg was larger than in the non-dominant leg (Figure 2).

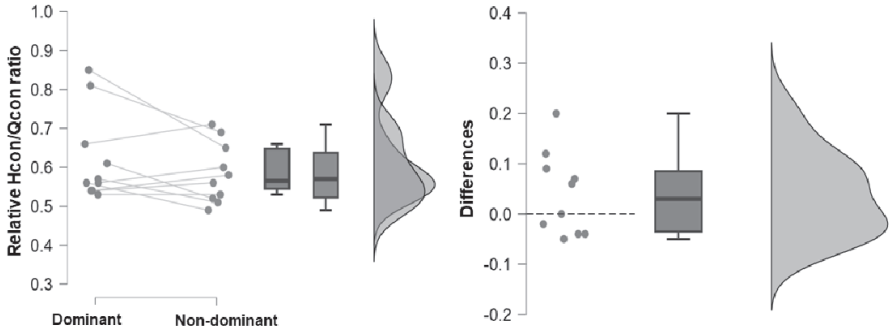

Figure 2. Relative Hcon/Qcon ratio of dominant and non-dominant leg and corresponding between-leg difference.

Between-leg asymmetry

Considering mean values, a small asymmetry could be observed in both quadriceps and hamstring muscles (Figure 3). When both criteria for asymmetry were analyzed, only one subject had quadriceps asymmetry over 15% while two subjects had hamstring asymmetries over 15%. None of the subjects attained the asymmetry larger than ± 2 standard deviations of the group's mean.

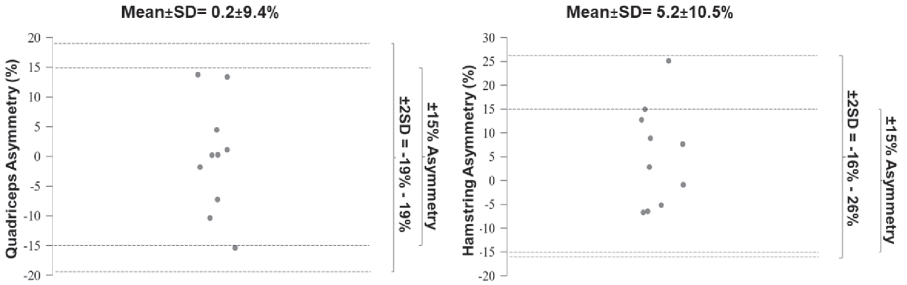

Figure 3. LSI assessed relative to general normative values and relative to sample's mean and data dispersion.

Discussion

This study aimed to establish reference values for isokinetic knee extension and flexion muscles in police special force operators, assess their conventional Hcon/Qcon ratio, and determine leg asymmetry. As will be discussed, descriptive statistics revealed torque values similar to athletes, and paired sample t-tests showed no significant between-leg differences in torque values on a group level. However, when the effect size was calculated and the dispersion of individual results was observed, small differences in hamstrings were noted. Furthermore, while, on a group level, no Hcon/Qcon ratio disparity between legs was observed, individual results indicated a trend towards greater dispersion in the dominant leg. Similarly, asymmetry could not be detected at a group level even though individual results indicated an increased asymmetry in isometric strength of hamstrings. These results suggest that police special force operators belong to higher tiers of individuals in terms of torque produced by quadriceps and hamstring muscles. However, when their quadriceps and hamstring function is tested and analyzed in smaller groups (units) they should be treated both as a group and individually.

Considering that the sample of subjects in this study were presumed to be in excellent physical condition, it could be supposed that they would provide higher outputs of absolute torque when compared to the general population and be similar to those of higher level athletes. This was not necessarily the case however. In a review of the literature Šarabon et al. (2021) considered the mean pooled relative torque of the male adult population to be 2.78 Nm/kg for the quadriceps (knee extension) and 1.25 Nm/kg for the hamstrings (knee flexion). While the data were not divided into dominant and non-dominant leg, their results suggest that the population in this research performed below the adult male population in quadriceps strength (dominant = 2.57 ± 0.17 Nm/kg; non-dominant = 2.57 ± 0.27 Nm/kg) but above the adult male population in hamstring strength (dominant = 1.59 ± 0.25 Nm/kg: non-dominant = 151 ± 0.26 Nm/kg). Considering these differences, the ranges of motion at the knee for the pooled review data ranged from 110 to 180° and the hip angle was generally 90° (94% of studies) but ranged from between 75 and 110°. As such, variations in the positioning of the subject may have impacted performance through alterations to muscle length-tension relationships.

When compared to professional football players in the first division of Belgium (Lehance et al., 2009), similar absolute values of peak torque of the thigh muscles were achieved (quadriceps = 224.2 ± 38.8 Nm / hamstring = 136.8 ± 34.1 Nm) with similar values also found in combat sports athletes (boxing quadriceps = 221.5 ± 48.9 Nm / hamstring = 124.9 ± 28.2 Nm; wrestling quadriceps = 241.0 ± 21.8 Nm / hamstring = 141.1 ± 31.4 Nm; Wushu quadriceps = 250.6 ± 28.6 Nm / hamstring = 142.4 ± 30.22 Nm) (Tatlıcı & Löklüoğlu, 2022). When relativized to body mass, values were higher in football players (quadriceps = 2.98 ± 0.35 Nm/kg and hamstrings = 1.98 ± 0.30 Nm/kg) and the combat sports athletes (boxing = 3.18 ± 0.49 Nm/kg; wrestling = 3.14 ± 0.29 Nm/kg; Wushu = 3.25 ± 0.66 Nm/kg). The reason for the difference in relative values is the significantly higher body mass of the special force

DOI 10.26773/mjssm.240305

operators compared to professional football players (89.10 ± 6.33 kg vs. 77.9 ± 6.2 kg) (Lehance et al., 2009) or the combat sports athletes (boxing = 69.30 ± 9.58 kg; wrestling =77.20 ±8.71kg; Wushu = 78.50 ±9.62 kg) (Tatlıcı & Löklüoğlu, 2022). Thus, the relative strength of these athletes' leg muscles may be more effective at handling their body statures and volumes (i.e., body frame and mass accompanied with training load), which is expected given their training history and professional demands.

It is of note, that police special force operators typically carry considerable operational load whilst on duty (Keeler et al., 2022). These loads can average around 20-25kg without additional equipment like door breaching equipment or ballistic shields. This poses additional strain to their legs, thus requiring higher strength levels than those of normal adult population. Furthermore, research suggests that relative strength in particular is crucial for the load carriage ability of police special force officers (Orr, Robinson, et al., 2022). Therefore, to optimize police special force officer capability, strength and conditioning programs meeting the specialized needs of these personnel should be among their training priorities.

The findings of this study fall within the range of professional male football players. A review systematic review by Baroni et al. (2020) of professional male soccer players (totaling 27 studies and 1,274 players) found a Hcon/Qcon ratio ranging from 0.5 to 0.89. Of note in the review, data were drawn from studies whose velocities ranged from 12-600s-1. As such, the wide range and differences in findings may be due to different methodological approaches and resultant impact of force-velocity relationships.

On a group level, identical Hcon/Qcon ratios for both legs calculated from both absolute and relative torque values suggest a potential lack of strength training focused on relative strength (Dawes et al., 2019). Greater dispersion of absolute Hcon/Qcon in the dominant leg suggests that variations in absolute values did not correspond to variations in relative values. Instead, individuals with higher body mass generated larger torque, supporting the supposition of a potential lack of relative strength. This finding underscores the importance of allometric scaling in muscle strength testing (Folland et al., 2008). The between-leg difference in Hcon/Qcon, with positive values indicating a larger ratio in the dominant leg, exhibited a widely dispersed distribution. This suggests greater consistency in the contraction of knee extensors than flexors in the dominant leg. In addition, the approach used for the analysis detected two subjects with high Hcon/Qcon ratio in their dominant legs. Despite Kellis et al.'s (2023) recent systematic review revealing no conclusive link between the Hcon/Qcon ratios and ACL injuries, monitoring this ratio remains essential for assessing the function and effectiveness of knee flexors and extensors (Šarabon et al., 2021).

The LSI results suggest that the differences in muscle strength within the same muscle group in both legs falls within the limit of two standard deviations. In terms of the normative value of 15%, one subject exhibited stronger quadriceps in the non-dominant leg, while two subjects had stronger hamstrings in the dominant leg compared to the non-dominant. The two criteria (i.e., two standard deviations and normative values of 15%) were employed following recent findings in a systematic review by Parkinson et al. (2021) who caution against relying solely on pre-established thresholds (10-15%) for interpreting asymmetry scores, due to a lack of robust evidence. This approach allowed for the comparison of results against external normative values and within the group, both against the group mean and among subjects. It also facilitated the timely identification of individuals with increased imbalances for targeted strength and conditioning programs. Police special force operators, unlike athletes who may develop beneficial sporting asymmetries (Maloney, 2019), require effective movement in diverse scenarios while carrying an occupational load, often under stress and unpredictability. In addition, their professional careers generally last longer and is dependent on their physical health. Thus, detecting and addressing professional asymmetries early would be of benefit in this population.

Several limitations exist in this study. The small sample size necessitates caution in extrapolating findings, highlighting the need for additional subjects in future research. The exclusive inclusion of male operators reflects the current composition of the special force police unit, given the absence of females meeting the physical fitness criteria during the study. Future research should incorporate occupation-specific tests to assess the impact of isokinetic profiles, Hcon/Qcon ratio, and asymmetries on occupational performance.

This study provides preliminary isokinetic strength data for the quadriceps and hamstring muscles among police special force operators. The results reveal absolute torque values comparable to athletes but a lower relative strength, indicating diminished effectiveness of the leg muscles in relation to the officer's body mass. This underscores the importance of implementing strength and conditioning programs that specifically address relative strength. Additionally, the study introduces a methodological framework for the evaluation of data at both group and individual levels, facilitating a comprehensive understanding of how the group compares to normative values specific to this population and identifying individuals necessitating focused attention. This approach allows for meticulous planning of personalized interventions, thereby contributing to enhanced group performance and individual operator health.

References

Baran, K., Dulla, J., Orr, R., Dawes, J., & Pope, R. (2018). Duty loads carried by the LA sheriff's department deputies. *Journal of Australian Strength & Conditioning*, *26*(5), 34–38.

Baroni, B. M., Ruas, C. V., Ribeiro-Alvares, J. B., & Pinto, R. S. (2020). hamstring-to-quadriceps torque ratios of professional male soccer players: A systematic review. *Journal of Strength and Conditioning Research*, *34*(1), 281–293. https://doi.org/10.1519/JSC.0000000000002609

Chen, Z., Chakrabarty, S., Levine, R. S., Aliyu, M. H., Ding, T., & Jackson, L. L. (2013). Work-related knee injuries treated in US emergency departments. *Journal of Occupational and Environmental Medicine*, *55*(9), 1091–1099. https://doi.org/10.1097/JOM.0b013e31829b27bf

Coombs, R., & Garbutt, G. (2002). Developments in the use of the hamstring/quadriceps ratio for the assessment of muscle balance. *Journal of Sports Science & Medicine*, *1*(3), 56–62.

Dawes, J. J., Lockie, R. G., Kornhauser, C. L., Holmes, R. J., & Orr, R. M. (2019). Relationships between absolute and relative strength and power in male police officers of varying strength levels. *Journal of Science in Sport and Exercise*, *1*(3), 281–288. https://doi.org/10.1007/s42978-

019-00033-5

Folland, J. P., Mc Cauley, T. M., & Williams, A. G. (2008). Allometric scaling of strength measurements to body size. *European Journal of Applied Physiology*, *102*(6), 739–745. https://doi.org/10.1007/s00421-007-0654-x

Gage, B. E., McIlvain, N. M., Collins, C. L., Fields, S. K., & Dawn Comstock, R. (2012). Epidemiology of 6.6 million knee injuries presenting to united states emergency departments from 1999 through 2008. *Academic Emergency Medicine*, *19*(4), 378–385. https://doi.org/10.1111/j.1553-2712.2012.01315.x

Hewett, T. E., Myer, G. D., & Zazulak, B. T. (2008). Hamstrings to quadriceps peak torque ratios diverge between sexes with increasing isokinetic angular velocity. *Journal of Science and Medicine in Sport*, *11*(5), 452–459. https://doi.org/10.1016/j.jsams.2007.04.009

Keeler, J. M., Pohl, M. B., Bergstrom, H. C., Thomas, J. M., & Abel, M. G. (2022). The effect of tactical tasks and gear on muscle activation of SWAT officers. *The Journal of Strength & Conditioning Research*, *36*(1), 238-244. https://doi.org/10.1519/JSC.0000000000003396

Kellis, E., Sahinis, C., & Baltzopoulos, V. (2023). Is hamstrings-to-quadriceps torque ratio useful for predicting anterior cruciate ligament and hamstring injuries? A systematic and critical review. *Journal of Sport and Health Science*, *12*(3), 343–358. https://doi.org/10.1016/j.jshs.2022.01.002

Lehance, C., Binet, J., Bury, T., & Croisier, J. L. (2009). Muscular strength, functional performances and injury risk in professional and junior elite soccer players. *Scandinavian Journal of Medicine & Science in Sports*, *19*(2), 243–251. https://doi.org/10.1111/j.1600-0838.2008.00780.x

Lockie, R., Dawes, J. J., Sakura, T., Schram, B., & Orr, R. M. (2023). Relationships between physical fitness assessment measures and a workplace task-specific physical assessment among police officers: A retrospective cohort study. *Journal of Strength and Conditioning Research*, *37*(3), 678–683. https://doi.org/10.1519/JSC.0000000000004301

Lyons, K., Stierli, M., Hinton, B., Pope, R., & Orr, R. (2021). Profiling lower extremity injuries sustained in a state police population: A retrospective cohort study. *BMC Musculoskeletal Disorders*, *22*(1), 115. https://doi.org/10.1186/s12891-021-03986-3

Maloney, S. J. (2019). The relationship between asymmetry and athletic performance: A critical review. *Journal of Strength & Conditioning Research*, *33*(9), 2579-2593. https://doi.org/10.1519/JSC.0000000000002608

Maupin, D., Robinson, J., Wills, T., Irving, S., Schram, B., & Orr, R. (2018). Profiling the metabolic fitness of a special operations police unit. *Journal of Occupational Health*, *60*(5), 356–360. https://doi.org/10.1539/joh.2018-0029-OA

Norkin, C. C., & White, D. J. (2016). *Measurement Of Joint Motion: A Guide to Goniometry*. F.A. Davis.

Orr, R., Canetti, E. F. D., Pope, R., Lockie, R. G., Dawes, J. J., & Schram, B. (2023). Characterization of injuries suffered by mounted and non-mounted police officers. *International Journal of Environmental Research and Public Health*, *20*(2), 1144. https://doi.org/10.3390/ijerph20021144

Orr, R., Hinton, B., Wilson, A., Pope, R., & Dawes, J. (2020). Investigating the routine dispatch tasks performed by police officers. *Safety*, *6*(4). https://doi.org/10.3390/safety6040054

Orr, R. M., Lockie, R., Milligan, G., Lim, C., & Dawes, J. (2022). Use of physical fitness assessments in tactical populations. *Strength & Conditioning Journal*, *44*(2), 106. https://doi.org/10.1519/SSC.0000000000000656

Orr, R. M., Robinson, J., Hasanki, K., Talaber, K. A., Schram, B., & Roberts, A. (2022). The relationship between strength measures and task performance in specialist tactical police. *Journal of Strength and Conditioning Research*, *36*(3), 757–762. https://doi.org/10.1519/JSC.0000000000003511

Parkinson, A. O., Apps, C. L., Morris, J. G., Barnett, C. T., & Lewis, M. G. C. (2021). The calculation, thresholds and reporting of inter-limb strength asymmetry: A systematic review. *Journal of Sports Science & Medicine*, *20*(4), 594–617. https://doi.org/10.52082/jssm.2021.594

Pellicer-Chenoll, M., Serra-Añó, P., Cabeza-Ruiz, R., Pardo, A., Aranda, R., & González, L. M. (2017). Comparison of conventional hamstring/quadriceps ratio between genders in level-matched soccer players. *Revista Andaluza de Medicina Del Deporte*, *10*(1), 14–18. https://doi.org/10.1016/j.ramd.2015.05.002

Šarabon, N., Kozinc, Ž., & Perman, M. (2021). Establishing reference values for isometric knee extension and flexion strength. *Frontiers in Physiology*, *12*. https://www.frontiersin.org/articles/10.3389/fphys.2021.767941

Sullivan, G. M., & Feinn, R. (2012). Using effect size—Or why the *P* value is not enough. *Journal of Graduate Medical Education*, *4*(3), 279–282. https://doi.org/10.4300/JGME-D-12-00156.1

Tatlıcı, A., & Löklüoğlu, B. (2022). Comparison of hamstring quadriceps strength ratios in different combat sports branches. *Physical Education of Students*, *26*(1), 35-40. https://doi.org/10.15561//20755279.2022.0105

DOI 10.26773/mjssm.240305