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REVIEW

Sex differences in thigh muscles characteristics: a systematic review

EXERCISE PHYSIOLOGY / MUSCLE / SPORTS SCIENCE

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Abstract

Objective: To determine differences between male and female subjects in the thigh muscles characteristics, separated into architectural (pennation, thickness, and/or fascicle length), mechanical (mass, strength, power, and/or stiffness), neuromuscular (activity) and fatigue aspects, in order to better understand the sex-related differences in the risk of muscle injuries.
Methods: A systematic literature search on Pubmed was performed with different keywords: skeletal muscle AND sex characteristics AND muscle contraction, with the following limits: humans and adults (19–44 years old). Studies dealing with hamstring and quadriceps muscles, in physiological condition, and comparison between male and female healthy adult subjects were included. Studies dealing with other skeletal muscles, injuries or physiopathology situation were excluded. Thigh muscular architectural, mechanical, neuromuscular and fatigue characteristics have been analysed to determine differences between male and female subjects.
Results: Seventeen studies were included, reporting significant sex-related differences for thigh muscles architecture and mechanical characteristics and muscle fatigue, and especially quadriceps, while for thigh muscles neuromuscular characteristics the results were not consensual, and few information was available regarding hamstring muscles.
Conclusions: Sex-related differences in thigh muscles characteristics, and especially quadriceps, have been reported for mechanical characteristics and muscle fatigue, while for neuromuscular characteristics sex-related differences were found to be moderate. Although several macroscopic muscle characteristics have been reported to be different between male and female healthy adult subjects, it is difficult to conclude on its exact relationship with higher muscle injury rates reported in male athletes during international athletics championships.

Résumé

Objectif: Déterminer les différences au niveau des caractéristiques des muscles de la cuisse, concernant les éléments architecturaux (pennation, épaisseur et/ou longueur du fascicule),

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mécaniques (masse, force, puissance et/ou rigidité), neuromusculaires (activité), et les aspects liés à la fatigue, entre les sujets masculins et féminins, afin de mieux comprendre les différences de risque musculaires liées au sexe.
Méthodes: Une recherche bibliographique systématique sur Pubmed a été réalisée avec différents mots-clés: skeletal muscle AND sex characteristics AND muscle contraction, avec les limites suivantes: humans and adults (19–44 years old). Les études ont été inclus si elles portaient sur; les muscles ischio-jambiers et quadriceps, dans un état physiologique sain, de sujets adultes en bonne santé, avec une comparaison entre hommes et femmes. Les études portant sur d'autres muscles squelettiques, analysant des situations de blessures ou autres situations physiopathologiques ont été exclues. Les caractéristiques architecturales, mécaniques, neuromusculaires et de fatigue musculaire des muscles de la cuisse ont été analysées pour déterminer les différences entre les hommes et les femmes.
Résultats: Dix-sept études ont été incluses, rapportant des différences significatives liées au sexe pour l'architecture et les caractéristiques mécaniques de la cuisse et la fatigue musculaire, en particulier le quadriceps, tandis que les résultats portant sur les caractéristiques neuromusculaires des muscles de la cuisse n'étaient pas consensuels, et peu d'informations étaient disponibles concernant les muscles ischio-jambiers.
Conclusions: Des différences liées au sexe dans les caractéristiques des muscles de la cuisse, et en particulier des quadriceps, ont été rapportées pour les caractéristiques architecturales, mécaniques et la fatigue musculaire, tandis que pour les caractéristiques neuromusculaires les différences liées au sexe se sont révélées modérées. Bien que plusieurs caractéristiques musculaires macroscopiques soient différentes entre les hommes et les femmes adultes sains en bonne santé, il est difficile de tirer des conclusions exactes quant à sa relation avec les taux plus élevés de blessures musculaires signalés chez les athlètes masculins lors des championnats internationaux d'athlétisme.

Conflict of interest: No potential conflict of interest declared
Funding: No funding
Ethical statement: Since the present systematic review did not involve human subjects the Ethical Approval or subjects' informed consent was not necessary, but we used data from previous studies, which followed the Ethical standard for research on human subjects according to the Declaration of Helsinki.

Introduction

The practice of athletics (track and field) leads to important risk of injuries [1,2]. Indeed, during the whole athletics season, about 61 to 76% of athletes reported at least one injury [3–5]. In addition, on a total of 14 international athletics championships from 2007 to 2014, a total of 1510 injuries were collected corresponding to an incidence of 100 injuries for 1000 registered athletes [6]. The principal type of injury during international athletics championships was muscle injuries accounting for about 41% of all injuries [7]. Thigh muscles injuries represented 53% of muscle injuries and 19% of all injuries, and hamstring muscles injuries was the first injury diagnosis with 17% of all injuries [7].

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Another important finding was the sex-related difference in injury rates and characteristics between male and female athletes during international athletics championships: male had 25% higher injury rates than female athletes [6]. The difference was mainly due to the sex-related difference in injury rate of muscle injuries (32 vs. 20 injuries per 1000 athletes for male and female athletes, respectively), muscle injuries representing the most common injury type in both male and female athletes [6]. Moreover, it was the only sex-related different injury type between male and female (with the exception of stress fractures which are less common (0.7% in male and 3.0% in female athletes)) [6]. More specifically, sex-related difference in injury rate was also mainly due to the sex-related difference in thigh muscles injuries (28 vs. 15 injuries per 1000 athletes for male and female athletes, respectively), and especially hamstring muscles injuries (22 vs. 12 injuries per 1000 athletes for male and female athletes, respectively), which were the main injury diagnoses [6].
In this context, a better understanding of sex-related differences in muscle characteristics, especially in thigh muscles characteristics, could help i) to better understand this sex-related difference in the risk of muscle injuries, and ii) to develop injury prevention measures adapted to these specific injury risks. Some parameters of muscle characteristics have been reported to be different between male and female subjects such as muscle body mass, strength, power, or muscle fatigue for instance [8–10]. Although these studies have been performed to describe muscular physiological differences between male and female subjects, these studies could also be of interest to help better explaining sex-related differences in regard to injuries. Therefore, the aim of the present study was to determine, through a systematic review, differences between male and female subjects in the thigh muscles characteristics, separated into architectural (pennation, thickness, and/or fascicle length), mechanical (mass, strength, power, and/or stiffness), neuromuscular (activity) and fatigue aspects, in order to better understand the sex-related differences in the risk of muscle injuries.

Methods

Search strategy and articles selection
Following the PRISMA guidelines, we conducted a systematic research on MEDLINE via PubMed for all articles analysing comparisons between male and female subjects for the thigh muscles characteristics for all articles published until December 10, 2018. Preliminary searches of articles were conducted from March 2017 to August 2018, and final literature search and articles selection were done the December 10, 2018.
The following key words and equation were used to conduct the searches: («Muscle, Skeletal»[Mesh] AND («Sex Characteristics»[Majr] OR «Sex Factors»[Majr])) AND («muscle architecture» OR «muscle stiffness» OR «Muscle Fibers, Skeletal»[Mesh] OR «Muscle Contraction»[Mesh]) AND «humans»[MeSH Terms] NOT «Aged»[Mesh] Filters: Humans; English; Adult: 19–44 years.
Inclusion criteria were: articles concerning the thigh muscles (i.e. hamstring or quadriceps muscles) in physiological situation, written in English, concerning macroscopic muscle characteristics, such as: architectural, mechanical, neuromuscular and fatigue aspects of the muscle. Exclusion criteria were: articles including subject with histories of muscle pathologies

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and/or injuries or any pain, and articles about microscopic muscle characteristics such as: myocytes, blood flow, and mitochondrial respiration.

After removal of duplicate articles, we selected the articles initially based on the title and abstract, then the full articles were retrieved and reviewed for selection following inclusion and exclusion criteria. References of selected articles were screened for appropriate articles. Articles selection was independently performed by two authors (PC and PE). Disagreements were resolved by consensus.

Since the present systematic review did not involve human subjects the Ethical Approval or subjects' informed consent was not necessary, but we used data from previous studies, which should have followed the Ethical standard for research on human subjects according to the Declaration of Helsinki. If the latter was not declared in the article, article was not excluded but this was reported in the results.

Data Extraction

Data extraction was performed by using a pre-defined data-abstraction sheet, and based on the findings of the preliminary searches. The following data were extracted: purpose of the study, number of subjects per sex, muscle examined, muscle characteristic studied, results and conclusions. The muscle characteristics were separated into architectural (pennation, thickness, and/or fascicle length), mechanical (mass, strength, power, and/or stiffness), and neuromuscular (activity) aspects, in addition the condition of muscle fatigue has also been distinguished.

In order to better highlight the main results of each study, and to highlight the potential differences between male and female subjects if it exists, the results of each parameter were summarised as: "male > female" or "male = female" or "male < female" and the information regarding the significance, and the conclusion regarding the sex-related difference as: "yes" or "moderate" or "no".

Quality Evaluation

Study quality was independently assessed by one author using the "Checklist for Measuring Quality" [11]. The following cut-off points have been reported to categorise studies by quality with a Methodological Quality Score (MQS): strong (21+), moderate (14–20), fair (7–13) and poor (<7) [11]. This score was not involved as a inclusion/exclusion criteria.

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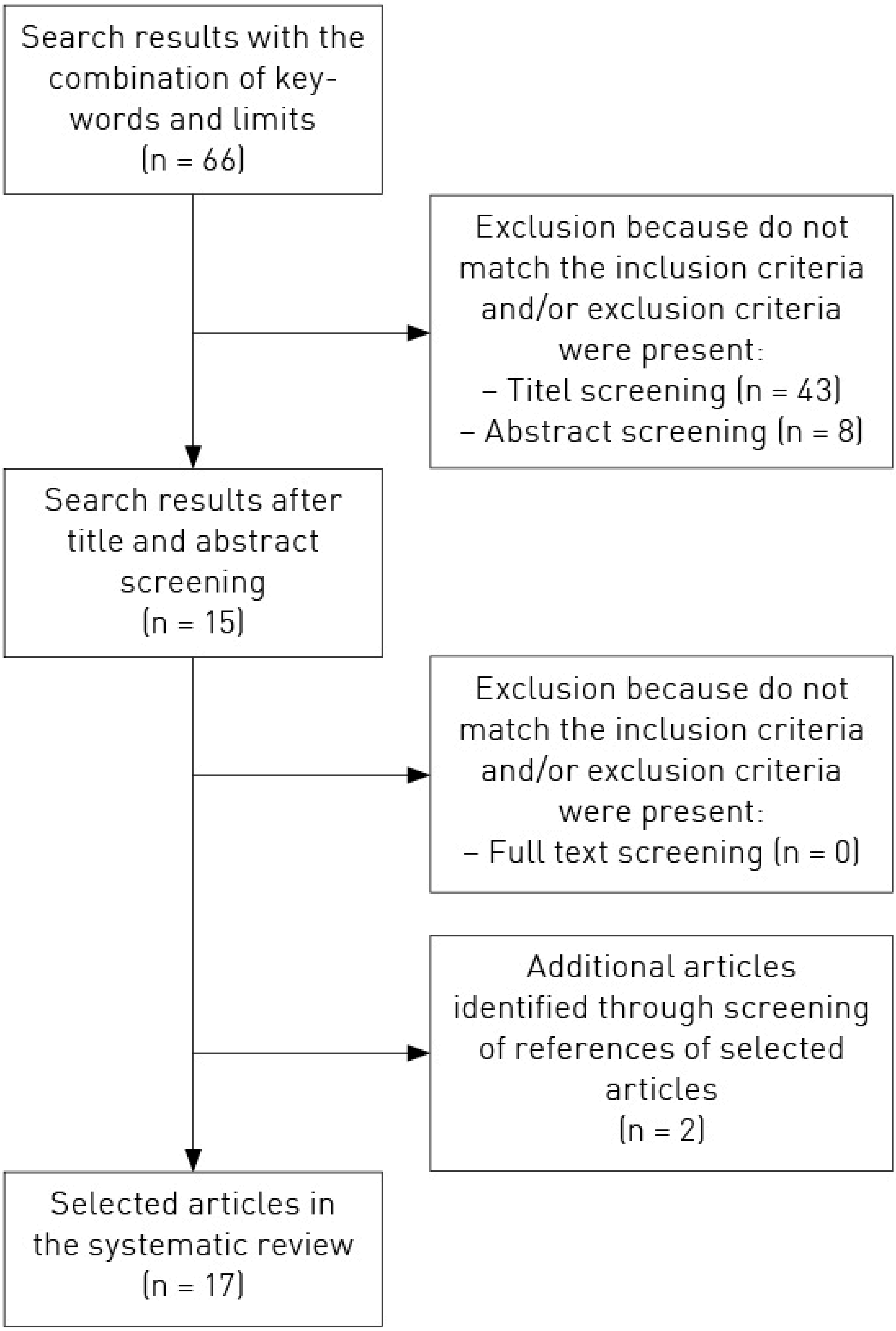

Fig. 1: Flow diagram of the literature screening process and selections of the article.

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Results

Selected articles
With the combination of keywords and limits, the literature search revealed 66 articles. 43 articles were excluded after reading their titles and 8 after reading their abstracts because they did not match with the purpose of our present systematic review and/or they did not meet the inclusion criteria. Two articles were find by looking at the references of selected articles. Finally, 17 articles were selected in this review. The flow diagram for the selection of studies is presented in Figure 1.
Articles described different muscle characteristics but they all concerned comparison between sexes on thigh muscles in healthy human subjects. Only one article did not declare that the study followed the Ethical standard for research on human subjects according to the Declaration of Helsinki [12].

	Methodological Quality Score	Number of males	Number of females	Muscles	Aim of the studies	Methods	Muscle characteristics evaluated	Results	Conclusions: Sex-related differences
Abe et al. 1998 [13]	17	22	29	Quadriceps muscle (vastus lateralis)	To evaluate the contribution of muscle pennation angle and fascicle length to gender differences in muscle size	In vivo measurement of muscle thickness, pennation angle and fascicle length	Muscle thickness Pennation angle Fascicle length	Male > female Male > female Male > female	Yes

Table 1: Studies concerning the comparison of thigh muscles architecture between male and female healthy adult subjects.

One article described the muscle architectural characteristics (Table 1) [13], six articles described the muscle mechanical characteristics using the parameters of strength, work, power, torque and/or stiffness measurements (Table 2) [8–10,14–16], eight articles described neuromuscular characteristics using the parameter of muscle activity (Table 3) [10,17–23], and finally five articles described the sex-related comparisons regarding muscle fatigue (Table 4) [8–10,24–26].

Methodological quality
All thirteen articles were assessed against the Down's and Black checklist and attained a score of either moderate or high quality. Almost all articles reported a high quality score (21+). The main areas of weakness in all articles were their internal validity and power analysis.

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	Methodological Quality Score	Number of males	Number of females	Muscles	Aim of the studies	Methods	Muscle characteristics evaluated	Results	Conclusions: Sex-related differences
Pincivero et al. 2003 [8]	24	19	20	Quadriceps and hamstring muscle	To examine gender differences in knee extensor and flexor peak torque, work, power and muscle fatigue	30 reciprocal, concentric maximal knee extension and flexion contractions at a pre-set angular	Work, power and peak torque	Male > female (significant)	Yes
Pincivero et al. 2003 [14]	24	15	15	Quadriceps muscle	To compare perceived exertion ratings between males and females	Evaluation of the one-repetition maximum (1-MR) then two substrate maximal contraction in a random order at 20% to 90% of their 1-MR	Strength	Male > female (significant)	Yes
Pincivero et al. 2004 [15]	24	14	15	Quadriceps muscle	To examine gender-specific knee extensor torque output and quadriceps femoris muscle recruitment during MCV	Three isometric contraction in a random order with the knee at 0° to 90° (every 20°) flexion	Average torque	Male > female (significant)	Yes
Wüst et al. 2008 [9]	23	29	35	Quadriceps muscle	To examine the muscle contractile properties	MRI (muscle size), Maximal voluntary contractions (MVC) repeated two or three times at knee joint angles of 60, 70, 80 in a random order	Muscle size and strength	Male > female (significant)	Yes
Wüst et al. 2008 [9]	23	29	35	Quadriceps muscle	To examine the muscle contractile properties	MRI (muscle size), Maximal voluntary contractions (MVC) repeated two or three times at knee joint angles of 60, 70, 80 in a random order	Torque	Female > Male (not significant)	Moderate

Table 2: Studies concerning the mechanical characteristics of the thigh muscles: comparison of work, power, strength,

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torque and stiffness measurement between male and female healthy adult subjects.

Data synthesis
Concerning muscle architecture, one article reported that isolated muscle thickness and pennation angle of vastus lateralis (quadriceps) were greater in male subjects, and there were no sex-related differences in fascicle length [13].

	Methodological Quality Score	Number of males	Number of females	Muscles	Aim of the studies	Methods	Muscle characteristics evaluated	Results	Conclusions: Sex-related differences
Deschenes et al. 2009 [10]	20	10	10	Right quadriceps muscle	Different adaptation to muscle unloading by sex via electromyography	Muscle function was quantified during knee extensions before and following unloading via electromyography during maximal isometric contractions	Total work, average power and peak torque	Male > female (significant)	Yes
Wang et al. 2015 [16]	21	22	22	Right quadriceps muscle	To investigate knee joints stiffness between young male and female athletes	Peak torque of the knee joint extensor musculature was assessed on an isokinetic dynamometer, muscle stiffness of the vastus lateralis muscle was measured in both relaxed and contracted conditions	Peak torque, and relaxed and contracted muscle stiffness	Male > female (significant)	Yes

MVC: Maximal voluntary contraction; MRI: Magnetic resonance Imaging, 1-MR: One maximal repetition.

Concerning the five studies about the muscle mechanical characteristics, all of them reported differences between male and female subjects (Table 2). Two articles [8,10] reported significant higher total work values for male than female subjects (1.76 J.kg-1 for male vs. 1.27 J.kg-1 for

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female subjects for knee extension and 1.20 J.kg-1 for male and 0.88 J.kg-1 for female subjects ($p<0.05$) [8]). These two articles also reported significant higher power values for male than for female subjects (5.17 W. kg-1 for male vs. 3.70 W.kg-1 for female subjects for knee extension and 3.52 W.kg-1 for male and 2.59 W.kg-1 for female subjects ($p<0.05$) [8]). Two articles [9,14,16] reported that male have significantly higher strength values than female subjects. Finally, three of the four studies [8,10,15,16] reported a significant difference between male and female subjects with greater torque values in male subjects. Only one study [9] reported different results with a 4% higher torque in female subjects compared to male subjects but this did not reach statistical significance ($p=0.063$). One article reported higher muscle stiffness values (relaxed and contracted) in male than female subjects [16].

Regarding studies about neuromuscular characteristics (Table 3), results are not consensual. One study [23] did not report any significant difference of total reaction time, pre-motor time and motor time between sexes. Reflex responses [22] may vary between sexes under the “do not innerve” condition. Male subjects demonstrated much more frequent and consistent reflex muscle activation than female subjects. Concerning the effect of unloading, muscle activity seems to be different between sexes after unloading (34% reduction of the electromyography noted among female and 8% for male subjects, $p=0.002$) [10] but not before. However, one article [21] reported that female subjects had a significant higher level of muscle activity than their male counterparts.

For studies about the muscle fatigue, the four [8,9,24,26] of the five articles reported a difference between male and female subjects (Table 4): male exhibited significant higher fatigue rates than female subjects.

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	Methodological Quality Score	Number of males	Number of females	Muscles	Aim of the studies	Methods	Muscle characteristics evaluated	Results	Conclusions: Sex-related differences
Pincivero et al. 2000 [17]	24	15	15	quadriceps muscle	To evaluate sex and muscle differences in electromyography amplitude	Electromyography activity during three maximal isometric voluntary contractions with the knee at 60° flexion	Muscle activity	(significant, only vastus lateralis muscle)	Moderate
Pincivero et al. 2001 [18]	24	15	15	quadriceps muscle	Electromyography during isometric contractions with the knee at 60° flexion	Repeated measurements design, series of 5s maximal voluntary isometric contractions, performed at intensities of 10 to 90% of MVC	Muscle activity	Male > female	Moderate
Pincivero et al. 2004 [15]	24	15	15	quadriceps muscle	Electromyography during isometric contractions with the knee at 60° flexion	Repeated measurements design, series of 5s maximal voluntary isometric contractions, separately performed in a random order	Muscle activity	Male > female (significant)	Moderate
Cramer et al. 2002 [20]	23	11	12	quadriceps muscle	To explore the sex, muscle and velocity responses	Concentric, isokinetic peal torque for extension of the dominant leg was measured at randomly order velocities of 60 to 300° (every 60)	Electromyography amplitudes	sex- and muscle-specific (only 2 muscle in female)	Moderate
DeMont et al. 2004 [21]	19	17	17	hamstring muscle	To determine if the level of preactivation of hamstring muscles during dynamic activity is affected by sex	Maximum voluntary contraction of the quadriceps and hamstrings muscles during downhill walking and running	Muscle activity	Female > male (significant)	Yes

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Table 3: Studies concerning the neuromuscular characteristics of the thigh muscles: comparison of muscle activity between and female healthy adult subjects.

	Methodological Quality Score	Number of males	Number of females	Muscles	Aim of the studies	Methods	Muscle characteristics evaluated	Results	Conclusions: Sex-related differences
Deschenes et al. 2009 [10]	20	10	10	right knee muscle	To explore whether male and female experienced different adaptation to muscle unloading	Muscle function was quantified during knee extensions before and following unloading via electromyography during maximal isometric contractions	Muscle activity	Female > male (significant), Female > male in decline of EMG (significant)	Moderate
Cammarata et al. 2010 [22]	22	12	12	quadriceps and hamstring muscle	To explore the effect on the volitional and reflex neuromuscular responses to a rapid valgus perturbation	multiple 7° ramp-and-hold valgus perturbations, in "innerve condition" (resistance) and "do not innerve"	Reflex responses	under "do not innerve": Male > female (significant), under "innerve": no difference	Moderate
Ayala et al. 2004 [23]	24	24	24	hamstring muscle	To examine sex-related differences in the hamstring reaction times profile	six maximal voluntary eccentric knee flexion muscle actions were performed with 30 sec rest between each contractions	Total Reaction, Pre-Motor & Motor Time	Female > Male (no significant)	No
MVC: Maximal voluntary contraction; sec: seconds									

Discussion

The main findings of the present study were that studies reported higher values of muscle mechanical characteristics for male than female subjects, higher muscle fatigue for male than

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female subjects, while neuromuscular characteristics remains unclear. The vast majority of the studies included focused on the quadriceps muscles, consequently very few is known regarding the hamstring muscles which represented the first injury diagnosis in international athletics championships [7].

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	Methodo-logical Quality Score	Number of males	Number of females	Muscles	Aim of the studies	Methods	Muscle characteristics evaluated	Results	Conclusions: Sex-related differences
Pincivero et al. 2003 [8]	24	19	20	quadriceps and hamstring muscle	to examine sex differences in muscle fatigue	30 reciprocal MCV, Muscle fatigue rate calculated as the decline in each isokinetic variable by the linear slope from the single highest repetition value through the 30th	muscle fatigue	Male > female (significant)	Yes
Wüst et al. [9]	23	29	35	quadriceps muscle	To determine whether there are differences in susceptibility to peripheral fatigue in male and female	MVC repeated two or three times at knee joint angles, Five minutes after, resistance to fatigue determined by a series of electrically evoked isometric contractions of 60, 70, 80 in a random order	muscle fatigue	Male > female (significant)	Yes
Ansdell et al. 2017 [24]	24	10	8	quadriceps muscle	To determine the sex difference in performance fatigability for intermittent, isometric contractions of the knee-extensor muscles	30% of MVC for 30min, and in a separate session at 50% MVC until task-failure, with measurements of MVC every 60 sec and EMG recording during all contractions	muscle fatigue	Male > female (significant)	Yes
Boccia et al. 2018 [25]	24	10	8	quadriceps muscle	To investigate sex differences in central and peripheral fatigue and in rate of force development in the knee extensors after a half-marathon run	Knee extensors forces were obtained under voluntary and electrically evoked isometric contractions.	central and peripheral muscle fatigue	Male = female	No

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Table 4: Studies concerning the sex-related comparison of the muscle fatigue.

	Methodological Quality Score	Number of males	Number of females	Muscles	Aim of the studies	Methods	Muscle characteristics evaluated	Results	Conclusions: Sex-related differences
O'Leary et al. 2018 [26]	24	23	19	quadriceps muscle	To investigate the sex difference in neuromuscular fatigue of British Army recruites	Isometric maximal voluntary contraction (MVC) force of the knee extensors were examined pre- and post-loaded march to examine neuromuscular fatigue	muscle fatigue	Male > female (significant)	Yes
MVC: Maximal voluntary contraction; EMG: electromyography; min: minutes; sec: seconds									

Sex-related differences in thigh muscles architectural aspects

Only one study reported results concerning sex-related comparison on muscle thickness, pennation angle and fascicle length, which was published 20 years ago. The results reported that isolated muscle thickness and pennation angle of quadriceps were greater in male than female subjects, and there were no sex-related differences in fascicle length. Given the fact that this is the only one study and the interest of such parameters in injury occurrence and thus prevention [27], it is of interest to analyse such parameters in future studies, in order to better understand the sex-related difference in thigh (and especially hamstring) injury risk [6].

Sex-related differences in thigh muscles mechanical aspects

These results suggested that thigh muscles, and especially quadriceps muscles, differed between male and female subjects regarding work, power and strength. Despite the few number of studies concerning muscle size and muscle mass, all studies included converged on the same direction with higher strength, work or power rates in male than in female subjects; results are consensual and consistent [8–10,14,15]. Male subjects presented a higher ability to generate force independent of their body mass [14]. Male subjects possessed an inherent ability to generate higher levels of torque than female subjects [8]. Gender-specific patterns in muscle activation and muscle fiber morphology have been reported as viable explanations for these strength differences [14]. Neural factors might explain these differences too. Sex-related disparities observed in the capacity of the nervous system to activate contracting muscle may play a role in sex-related differences concerning strength, especially after unloading. Female

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subjects suffered a greater degree of neuromuscular disturbance than men [10]. Regarding injury risk, does this capability to develop higher strength can make male athletes at higher risk of muscle injuries than female subjects, because they can outmatch the muscle capability. In addition, sex-related differences seem to exist regarding stiffness [16]. Can this higher stiffness in male than female subjects explain higher sprint performance but higher thigh (and especially hamstring) injuries in males athletes? Future studies should analyse this parameters in comparison to injury occurrence in order to improve understanding on injury risk and help for injury prevention.

Sex-related differences in muscle activity
The results are different according to the studies. It seems that there is no difference in the intensity or ability to activate the quadriceps muscles [22]. Female may require a greater amount of time to reach a specified percentage of maximal force [23]. Even if non-significant, female subjects reported consistently longer hamstring total reaction time, pre-motor time and motor time and differences in neuromechanical function of the hamstrings [23]. Moreover, female subjects reflex responses are reported to be less frequent and consistent than male's ones [22]. Sex-related differences in neuromuscular control and neurophysiological mechanisms of the lower extremity have been reported to contribute to increase injury risk [22]. However, given the inconsistency of results and the lack of studies analysing the aspects in comparison to injury occurrence, no conclusion could be done, which would have been of interest in an injury prevention perspective.

Sex-related differences in muscle fatigability
Female subjects appeared to experience muscle fatigue at a slower rate [8]. Intrinsic sex-related differences in skeletal muscle properties, such as contractile speed and rate of energy utilisation, probably play a key role in these sex-related differences in fatigue [9]. Female subjects have slower contractile speed than male subjects [9]. Moreover, the difference in fatiguability may be a consequence of higher energy utilization in male subjects, which is the reason why they may fatigue more rapidly. It must reside in the rate at which energy is used by the muscle fibers rather than the oxydative recovery rates [9]. Male subjects exhibit a higher susceptibility to muscle fatigue and the higher rate of muscle injuries can be related to this susceptibility. This aspect could play a role in the higher thigh muscles injury risk of male aspects, since muscle injuries have been reported to be increased in fatigue condition [28,29]. Female athletes could be better protected against injuries because their muscle kept higher percentage of maximal strength longer than male athletes. This hypothesis should of course be confirmed throught experimental study.

Limitations
Some limitations have to be discussed. First, only one data base was screened (MEDLINE via PubMed), the present systematic review can thus not be considered as exhaustive. However, this is the database that brings together the most articles on the physiological and medical fields. Second, the quality of the present review depends on the quality of selected studies.

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Third, despite of the models quite similar between studies, muscle characteristics studied and methods for analyses were different between the selected studies, that makes the comparison difficult. Only some characteristics of the muscle have been analysed representing mechanical and neuromuscular aspects of the muscle. Fourth, other studies reported results regarding sex-related muscle characteristics but involving other muscles than thigh muscles. Finally, many muscle characteristics have been presented in these articles, however it could be not exhaustive enough to describe all the all muscle characteristics (potential limitation due to keywords…). Moreover, the analysis is not focused enough on main aspects to settle on precise conclusions. Therefore, further more detailed researches are required.

Perspectives
Muscle injury has been reported to be the only injury type concerned by sex-differences during international athletics championships [6]. The different studies included in our systematic review reported sex-related differences in the muscle characteristics of thigh muscles: higher levels of power, work, strenght, stiffness and fatibability in male than female subjects. These sex-related differences in muscle characteristics could be involved in the hypothesis to explain the higher muscle injury rate reported in male than in female athletes, but none of these articles can strongly explain the sex-related injury difference. Throughought this systematic review, we cannot conclude on the reason of the higher muscle injury rate in male athletes. However, it gives opportunities for further studies.

Conclusions

The main findings of the present study were that muscle architecture and mechanical characteristics were higher for male than female subjects, muscle fatigue higher for male than female subjects, while neuromuscular characteristics remains unclear. Although several macroscopic muscle characteristics have been reported to be different between male and female healthy adult subjects, it is difficult to conclude on its exact relationship with the higher muscle injury rates reported in male athletes during international athletics championships.

Conflict of interest

The authors declare no conflicts of interest.

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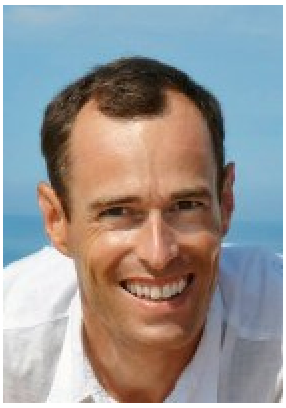

Referenzen

1. Edouard P, Morel N, Serra J-M, et al. [Prévention des lésions de l'appareil locomoteur liées à la pratique de l'athlétisme sur piste. Revue des données épidémiologiques]. Sci Sports 2011;26:307-15. doi: 10.1016/j.scispo.2011.04.003.
2. Edouard P, Alonso JM, Jacobsson J, et al. Injury Prevention in Athletics: The Race Has Started and We Are on Track! New Stud Athl 2015;30:69-78.
3. D'Souza D. Track and field athletics injuries – a one-year survey. Br J Sports Med 1994;28:197-202.
4. Bennell KL, Crossley K. Musculoskeletal injuries in track and field: Incidence, distribution and risk factors. Aust J Sci Med Sport 1996;28:69-75.
5. Jacobsson J, Timpka T, Kowalski J, et al. Injury patterns in Swedish elite athletics: annual incidence, injury types and risk factors. Br J Sports Med 2013;47:941-52. doi:10.1136/bjsports-2013-092676.
6. Edouard P, Feddermann-Demont N, Alonso JM, et al. Sex differences in injury during top-level international athletics championships: surveillance data from 14 championships between 2007 and 2014. Br J Sport Med 2015;49:472-7. doi:10.1136/bjsports-2014-094316.
7. Edouard P, Branco P, Alonso J-M. Muscle injury is the principal injury type and hamstring muscle injury is the first injury diagnosis during top-level international athletics championships between 2007 and 2015. Br J Sports Med 2016;50:619-30. doi:10.1136/bjsports-2015- 095559.
8. Pincivero DM, Gandaio CMB, Ito Y. Gender-specific knee extensor torque, flexor torque, and muscle fatigue responses during maximal effort contractions. Eur J Appl Physiol 2003;89:134-41. doi:10.1007/s00421-002-0739-5.
9. Wüst RCI, Morse CI, de Haan A, et al. Sex differences in contractile properties and fatigue resistance of human skeletal muscle. Exp Physiol 2008;93:843-50. doi:10.1113/expphysiol.2007.041764.
10. Deschenes MR, McCoy RW, Holdren AN, et al. Gender influences neuromuscular adaptations to muscle unloading. Eur J Appl Physiol 2009;105:889-97. doi:10.1007/s00421-008-0974-5.
11. Downs SH, Black N. The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. J Epidemiol Community Heal 1998;52:377-84.
12. DeMont RG, Lephart SM. Effect of sex on preactivation of the gastrocnemius and hamstring muscles. Br J Sports Med 2004;38:120–4. doi:10.1136/bjsm.2003.000195.
13. Abe T, Brechue WF, Fujita S, et al. Gender differences in FFM accumulation and architectural characteristics of muscle. Med Sci Sports Exerc 1998;30:1066-70.
14. Pincivero DM, Coelho AJ, Campy RM. Perceived exertion and maximal quadriceps femoris muscle strength during dynamic knee extension exercise in young adult males and females. Eur J Appl Physiol 2003;89:150-6. doi:10.1007/s00421-002-0768-0.

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https://doi.org/10.34045/SSEM/2019/7

15. Pincivero DM, Salfetnikov Y, Campy RM, et al. Angle- and gender- specific quadriceps femoris muscle recruitment and knee extensor torque. J Biomech 2004;37:1689-97. doi:10.1016/j.jbiomech.2004.02.005.
16. Wang D, De Vito G, Ditroilo M, et al. A comparison of muscle stiffness and musculoarticular stiffness of the knee joint in young athletic males and females. J Electromyogr Kinesiol 2015;25:495-500. doi:10.1016/j.jelekin.2015.03.003.
17. Pincivero DM, Green RC, Mark JD, et al. Gender and muscle differences in EMG amplitude and median frequency, and variability during maximal voluntary contractions of the quadriceps femoris. J Electromyogr Kinesiol Off J Int Soc Electrophysiol Kinesiol 2000;10:189-96.
18. Pincivero DM, Campy RM, Salfetnikov Y, et al. Influence of contraction intensity, muscle, and gender on median frequency of the quadriceps femoris. J Appl Physiol (Bethesda, Md 1985) 2001;90:804-10.
19. Pincivero DM, Coelho AJ, Campy RM, et al. The effects of voluntary contraction effort on quadriceps femoris electromyogram median frequency in humans: a muscle and sex comparison. Eur J Appl Physiol 2002;87:448-55. doi:10.1007/s00421-002-0658-5.
20. Cramer JT, Housh TJ, Weir JP, et al. Power output, mechanomyographic, and electromyographic responses to maximal, concentric, isokinetic muscle actions in men and women. J Strength Cond Res 2002; 16:399-408.
21. DeMont RG, Lephart SM. Effect of sex on preactivation of the gastrocnemius and hamstring muscles. Br J Sports Med 2004;38:120-4.
22. Cammarata ML, Dhaher YY. Evidence of gender-specific motor templates to resist valgus loading at the knee. Muscle Nerve 2010;41:614-23. doi:10.1002/mus.21509.
23. Ayala F, De Ste Croix M, Sainz de Baranda P, et al. Inter-session reliability and sex-related differences in hamstrings total reaction time, pre-motor time and motor time during eccentric isokinetic contractions in recreational athlete. J Electromyogr Kinesiol Off J Int Soc Electrophysiol Kinesiol 2014;24:200-6. doi:10.1016/j.jelekin.2013. 12.006.
24. Ansdell P, Thomas K, Howatson G, et al. Contraction intensity and sex differences in knee-extensor fatigability. J Electromyogr Kinesiol 2017;37:68-74. doi:10.1016/j.jelekin.2017.09.003.
25. Boccia G, Dardanello D, Tarperi C, et al. Women show similar central and peripheral fatigue to men after half-marathon*. Eur J Sport Sci 2018;18:695-704. doi:10.1080/17461391.2018.1442500
26. O'Leary TJ, Saunders SC, McGuire SJ, et al. Sex differences in neuromuscular fatigability in response to load carriage in the field in British Army recruits. J Sci Med Sport 2018;21:591-5. doi:10.1016/j.jsams.2017.10.018.
27. Timmins RG, Bourne MN, Shield AJ, et al. Short biceps femoris fascicles and eccentric knee flexor weakness increase the risk of hamstring injury in elite football (soccer): a prospective cohort study. Br J Sports Med 2016;50:1524-35. doi:10.1136/bjsports-2015-095362.
28. Woods C, Hawkins RD, Maltby S, et al. The Football Association Medical Research Programme: an audit of injuries in professional football-analysis of hamstring injuries. Br J Sport Med 2004;38:36-41. doi:10.1136/bjsm.2002.002352.
29. Brooks JHM, Fuller CW, Kemp SPT, et al. Incidence, Risk, and Prevention of Hamstring Muscle Injuries in Professional Rugby Union. Am J Sports Med 2006;34:1297-306. doi:10.1177/0363546505286022.

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