

Electromyographic activation levels of gluteus maximus, hamstrings and quadriceps in squat and hip thrust exercises: a systematic review

Níveis de ativação eletromiográfica de glúteo máximo, isquiotibiais e quadríceps em exercícios de agachamento e impulso de quadril: uma revisão sistemática

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ABSTRACT

This systematic review aimed to compare the activation levels of hip and knee extensors between the squat exercises and their variations and the hip thrust exercise (HT). To this end, articles published with a time window starting in November 2022 were collected from the electronic databases PubMed, Scopus and Web of Science. The following selection criteria were adopted: cross-sectional or longitudinal study (experimental or cohort); studies that evaluated the neuromuscular activation during the squat and HT exercises or their variations; studies that included healthy, injury-free participants; studies that analyzed the amplitude of

electromyographic signals. In total, 4 articles met the study criteria. The following results were found: a) The HT provided greater activation of the hip extensors; b) The squat and its variations increased muscle activation in the vastus lateralis; c) The results are inconclusive for activation of the biceps femoris. The study presented some limitations, such as the low number of articles found, small sample size, lack of studies with a more complete analysis by EMG between the muscle groups of the lower limbs, and lack of chronic records related to muscle hypertrophy and neuromuscular activity.

Keywords: squat, hip thrust, electromyography, resistance training.

RESUMO

Esta revisão sistemática teve como objetivo comparar os níveis de ativação dos extensores de quadril e joelho entre os exercícios de agachamento e suas variações e o exercício de elevação pélvica (HT). Para tanto, os artigos publicados com janela temporal iniciada em novembro de 2022 foram coletados nas bases de dados eletrônicas PubMed, Scopus e Web of Science. Os seguintes critérios de seleção foram adotados: estudo transversal ou longitudinal (experimental ou coorte); estudos que avaliaram a ativação neuromuscular durante os exercícios de agachamento e HT ou suas variações; estudos que incluíam participantes saudáveis e sem lesões; estudos que analisaram a amplitude dos sinais eletromiográficos. No total, 4 artigos atenderam aos critérios do estudo. Os seguintes resultados foram encontrados: a) O EP proporcionou maior ativação dos extensores do quadril; b) O agachamento e suas variações aumentaram a ativação muscular do vasto lateral; c) Os resultados são inconclusivos para ativação do bíceps femoral. O estudo apresentou algumas limitações, como o baixo número de artigos encontrados, pequeno tamanho da amostra, falta de estudos com uma análise mais completa por EMG entre os grupos musculares dos membros inferiores e falta de registros crônicos relacionados à hipertrofia muscular e atividade neuromuscular.

Palavras-chave: agachamento, elevação pélvica, eletromiografia, treinamento resistido.

1 INTRODUCTION

Hip extension is essential for carrying out motor tasks in many work and sports activities. However, erosive behaviors related to physical inactivity and chronic labor pathobiomechanical activities cause important functional deficits in the hip extensor muscles, primarily in the gluteus maximus (Gmax), which is considered the main hip extensor, especially in movements that cause active insufficiency of the hamstrings (McCurdy *et al.*, 2018; Neto, 2019).

Among the exercises for the lower limbs used to increase the level of muscular recruitment of the hip extensors, especially the Gmax, hamstrings (except the short head of the biceps femoris), and adductor magnus, two stand out: the squat and the hip thrust exercise (HT) (McCurdy *et al.*, 2018; Neto, 2019). Squat exercises are among the most popular with strength training practitioners and professionals, treated by many as ubiquitous and irreplaceable exercises for those seeking to improve body aesthetics, performance, musculoskeletal

rehabilitation of the lower body region, and health in general. One of the reasons for this is that the squat exercises mobilize a great deal of neuromuscular activity in the lower limbs, in addition to considerably stimulating the cardiorespiratory and hormonal systems (Geisler, 2019; Wirth, 2016). Squats are also used as tools to assess movement deficits (Ahankoob, 2011; Contreras, 2015; Kushner *et al.*, 2015) or even for routine physical and functional examinations (Richards, 2008).

Squat exercises are also advocated because they include mechanical characteristics that resemble everyday functional movements, such as walking, going up and down stairs, sitting, and standing (Pauli, 2016; Schoenfeld, 2010). In addition, squat training can promote neuromotor adaptations able to counteract medial or lateral displacement of the knee in different activities, minimizing lateral loads on the joint (Andersen, 2018; Delgado, 2019), which reduces the risk of joint dysfunction in the knee.

On the other hand, in recent years there has been a considerable increase in scientific publications on HT exercises (Abade, *et al.*, 2021; Loturco, *et al.*, 2018; González-García, *et al.*, 2019), which has contributed to increasing the popularity of this exercise among professionals and practitioners of different strength training modalities.

HT is a type of exercise performed with the individual in dorsal decubitus or with their back supported on a straight bench, with the bar or other implement resting on the hip, and with the knees and hips flexed and the feet supported on the ground. When the knee and hip are extended, the body is in the form of a bridge. This exercise has commonly been used as a strategy to develop the hip extensor musculature. The main muscles involved in HT exercises are the primary hip extensors (Gmax and hamstrings), secondary extensors (adductors and posterior fibers of the gluteus medius and minimus), vertebral stabilizers (erector spinae), and knee extensors (vastus and rectus femoris).

In addition to reducing the overload on the axial skeleton, HT seems to be a very effective tool to work the musculoskeletal system of the lower limbs in a safe and efficient way (Contreras *et al.*, 2011). The hip extensor muscles, mainly the Gmax, can present high neuromuscular activity in the HT exercise, when compared to other traditional exercises (Contreras *et al.*, 2011; Neto, 2020). Since Contreras *et al.*, (2015) reported, using an experimental model with electromyography, that the HT exercise exhibited higher levels of Gmax muscle activation compared to the squat exercise, other works have emerged that also show higher levels of myoelectric activity of Gmax, when compared to squat exercises or deadlift variations (Collazo-García, 2020; Haramura, 2017).

Although the majority of studies report that HT exercises promote higher levels of activation in Gmax, there are still many doubts regarding the levels of electromyographic (EMG) activation of the quadriceps, hamstrings, and Gmax itself in different variations of squats and HT. Therefore, this systematic review aimed to compare the activation levels of hip and knee extensors between the squat exercises and their variations and the hip thrust exercise (HT).

2 MATERIALS AND METHODS

2.1 SEARCH STRATEGIES IN THE LITERATURE

The preferred item statement guide for systematic review and meta-analysis reports (PRISMA) was used to conduct this systematic review (Page *et al.*, 2021).

The present work is a systematic review, which brings together studies collected in the electronic databases PubMed, Scopus and Web of Science, carried out in February 2022, in addition, a new search was carried out in November to make sure that no new publication about the subject. How could we include publications with a time window from the beginning of November 2022 to.

The search strategy carried out in the different databases, together with the Medical Subject Heading (MeSH) descriptors, related terms, and keywords used were as follows (squat) OR (back squat) AND (hip thrust) AND (electromyography).

The PICO strategy was defined as follows: P: Patients with training levels from beginners to advanced; I: Intervention with strength training; C: Comparison between squat and HT exercises; and O: electrical activity of the gluteus maximus, hamstrings, and quadriceps.

2.2 INCLUSION AND EXCLUSION CRITERIA

Studies were included if they met the following criteria: cross-sectional or longitudinal study design (experimental or cohort); studies that evaluated neuromuscular activation during squat and HT exercises or their variations; studies that included healthy, injury-free participants; studies that analyzed “average and peak amplitude of sEMG signals”, “muscle activation”, or “muscle activity” with surface electromyography devices (sEMG). Studies with insufficient data, review articles, congress articles, student theses, with poor data presentation, and unclear descriptions of applied protocols were excluded. As different terms are related to the same concept, in categories of unifying criteria, the term “muscle activation” will be used when referring to “sEMG amplitude”, “muscle excitation”, “muscle activity”, “neuromuscular activity” or similar.

2.3 STUDY SELECTION

The articles were selected by three independent reviewers (NE, RR, and LD) according to the inclusion and exclusion criteria. After eliminating duplicate articles, titles and abstracts were analyzed and, if there was not enough information, the full text was evaluated. In the case of any doubts, a fourth evaluator made the decision as to whether the study was maintained or withdrawn (MFA). Each decision was approved by the reviewers.

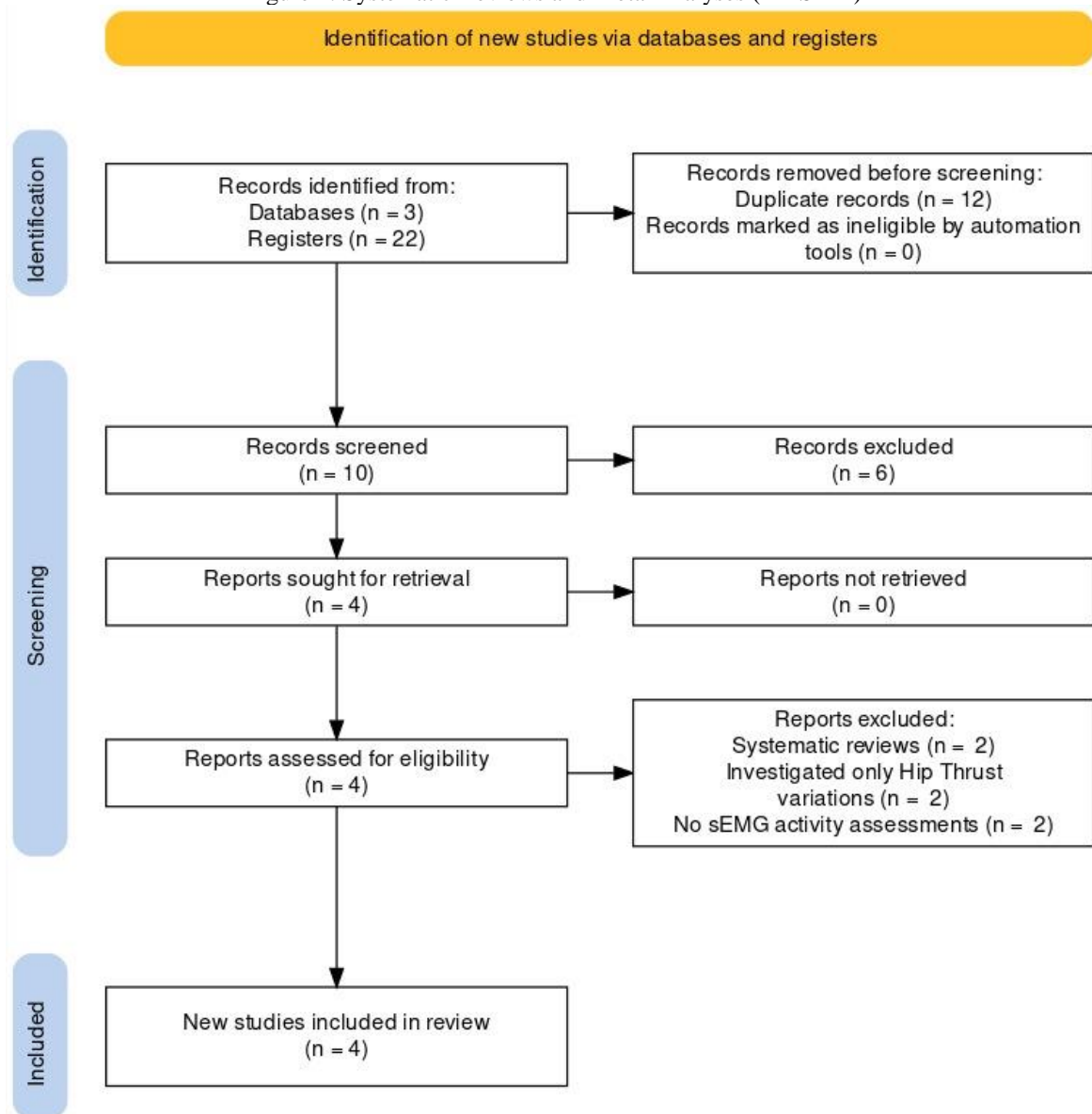
2.4 METHODOLOGICAL QUALITY

The methodological quality of each study was assessed using a modified 11-point physical therapy evidence database (PEDro) scale (Shiwa et al., 2011); the quality of each study was assessed independently by two authors (R.R. and E.N.). As it is not possible to blind participants and researchers in supervised physical exercise interventions, items 5, 6 and 7 were removed, as they are blinding items, in addition item 1 refers to the eligibility criteria and is not included in the total score, in this context, the maximum score of the modified PEDro scale is 7 points. These qualitative methodology scores were classified based on previous systematic reviews related to exercises, as follows: 6–7 = “excellent quality”; 5 = “good quality”; 4 = “moderate quality”; 0–3 = “poor quality,” (Kümmel et al., 2016; Schoenfeld et al., 2020).

3 RESULTS

A total of 22 articles were identified in the initial search (Web of Science = 8; Scopus = 7; PubMed = 7). Of these, 12 were duplicated in the databases. After reading the titles and abstracts, 6 papers did not meet the inclusion criteria of this research. Finally leaving only 4 articles for the complete reading of the text, which were considered eligible for analysis and made up the sample of this systematic review (figure 1). In addition, the PEDro scale scores for the studies in this review ranged from 5 to 7 (mean = 6.25 ± 0.9) (Table 1). Of the 4 included studies, 2 had a total score of 7, 1 a score of 6, and 1 a score of 5. The results indicate that the evidence used in this review comes from studies with methodological quality from “good” to “excellent”.

Figure 1. Systematic Reviews and Meta-Analyses (PRISMA)



Source: Author.

Table 1: Assessment of the methodological quality of randomized clinical trials according to the Physiotherapy Evidence Database scale (PEDro).

Articles	1	2	3	4	8	9	10	11	Total
Delgado et al. (2019)	no	no	no	yes	yes	yes	yes	Yes	5/7
McCurdy et al. (2021)	yes	yes	no	yes	yes	yes	yes	Yes	7/7
Contreras et al. (2015)	yes	no	no	yes	yes	yes	yes	Yes	6/7
Williams et al. (2021)	yes	yes	no	yes	yes	yes	yes	Yes	7/7

Source: Author.

PEDro scale items: 1= Eligibility criteria have been specified. 2= Subjects were randomly assigned to groups. 3= The allocation of subjects was secret. 4= Initially, the groups

were similar with respect to the most important prognostic indicators. 8=Measurements of at least one key outcome were obtained in more than 85% of the subjects initially assigned to the groups. 9=All subjects from whom outcome measurements were presented received the treatment or control condition as allocated or, when this was not the case, data analysis was performed for at least one of the key outcomes by “intent to treat”. 10=Results of intergroup statistical comparisons were described for at least one key outcome. 11=The study has both precision measures and variability measures for at least one key outcome.

In total, 49 participants (33 women and 16 men) performed the HT and squat exercises (three variations). Contreras *et al.* (2015) evaluated free squat vs HT exercises; Delgado *et al.* (2019) compared HT, squat, and Romanian deadlift exercises; Williams *et al.* (2021) compared the levels of activation in HT, squat, and lunge exercises; while McCurdy *et al.*, (2021) evaluated the Bulgarian squat vs HT. Exercise intensity ranged from 36% to 100% of 1RM and concentric, eccentric, and isometric muscle actions were analyzed.

In summary, the HT exercise showed significantly greater mean and peak myoelectric activation for Gmax compared to the free squat and lunge squat at different intensities (36.8% to 100% of 1RM) (Williams *et al.*, 2021; Contreras *et al.*, 2015; Delgado *et al.*, 2019).

However, this effect was not observed when comparing HT with the Bulgarian squat, as there was no significant difference in Gmax activation during the complete repetition of the exercise (McCurdy *et al.*, 2021). Regarding isometric actions, HT showed superior activation for a 3-second isometric contraction (with thighs parallel to the ground in both exercises) (Contreras *et al.*, 2015).

The results for the knee extensors showed that when comparing the free squat with the HT, there were no significant differences in the mean and peak activation of the vastus lateralis during dynamic and isometric contractions (Contreras *et al.* 2015). Nonetheless, Delgado *et al.* (2019) demonstrated that the free squat induced a greater electromyographic signal in the vastus lateralis at different intensities when compared to the HT. The work of McCurdy *et al.* (2021) reported that the electromyographic activity of the vastus lateralis was greater in the HT compared to the Bulgarian squat in the first third of the movement, however, in the final amplitudes of the movement the activation of the vastus lateralis was greater in the Bulgarian squat. For activation values related to the complete movement, the Bulgarian squat showed significantly higher activity levels compared to the HT (McCurdy *et al.*, 2021) (table 2).

For the EMG activation values of the hamstrings, the work of Contreras *et al.* (2015) observed higher mean and peak electromyographic activation of the biceps femoris during the HT, when compared to the free squat. Similar results were observed in the work of McCurdy

et al. (2021) for the activation of the biceps femoris lateral head, semimembranosus, and semitendinosus, only for the first third of the HT movement compared to the Bulgarian squat. In the final amplitudes of the movement, the mean and peak activation were higher in the Bulgarian squat. However, when the values were processed for full repetition, McCurdy *et al.* (2021), found no differences between the two exercises. The study of Delgado *et al.* (2019) also did not observe significant differences between HT and free squat exercises. The work by William *et al.* (2021) did not evaluate the EMG activation response in the hamstrings (Table 2).

Table 2. Description of the data referring to each study in relation to the subthemes: type of intervention, sample, sex, age, length of experience, main findings, p value, and ES

Reference	Exercises/ Sample	Results Gmax	Results hamstrings	Resultados Quadriceps
Delgado <i>et al.</i> (2019)	- HT; back squat and Romanian deadlift - Eight men with a mean age of 25 ±3.3, with at least 1 year of experience	- Greater activation of Gmax in the HT exercise compared to the back squat for loads of 60 Kg (ES =1.36; p = 0.008). - For the 1RM loads, the HP showed greater activation compared to the Back squat (ES = 1.39, p = 0.038).	- No significant differences in BF activation between back squat and HT for loads of 60 kg (ES = 0.98, p = 0.075). - Greater activation of the BF in HP for 1RM loads (ES = 0.99, p = 0.001)	For the VL, the activation was greater in the back squat for 60 kg (ES = 2.54, p = 0.001), and for loads of 1RM (ES = 2.27, p = 0.009).
McCurdy <i>et al.</i> (2021)	- HT vs Bulgarian squat - Twenty women, with a mean age of 20.9 ±2.3 and with a mean of 2.91 ±1.38 years of training experience.	- Greater activation in HT in the upper range of motion (p < 0.001). - At the end of the movement, the Bulgarian squat showed greater activation (p < 0.001). - No difference in mean EMG during full repetition for Gmax (p > 0.05).	- For three hamstrings, the greatest activation in HT was observed in the upper range of motion (p < 0.001). - At the end of the movement, the Bulgarian squat showed greater activation (p < 0.001). - No difference in mean EMG during full repetition (p > 0.05).	- For the VL, greater activation was observed in HP in the upper range of motion (p < 0.001). - In the Bulgarian squat, the VL showed greater activation at the end of the movement (p < 0.001). - For full repetition the Bulgarian squat produced higher levels of activation in the VL (59.4 vs 43.6%).
Contreras <i>et al.</i> (2015)	- HT vs back squat - Thirteen women, with a mean age of 28.9±5.1 years and a mean of 7 ±5.80 years of training	- HT promoted higher mean (ES = 1.64; P = 0.004) and peak EMG (ES = 1.18; P = 0.038) in the upper portions of Gmax, in addition to higher mean (ES = 1.64; P = .004) and peak EMG (ES = 1.18; P = 0.038) of the lower portions of Gmax compared to the back squat.	HT propiciou maior média (ES = 1.58; P = .004) e pico EMG (ES = 1.63; P = 0.004) in BF.	No difference between exercises for mean (ES = -0.15; P = 0.531) as for peak EMG (ES = -0.17; P = 0.400) in VL.

Williams <i>et al.</i> (2021)	- HT, Lunge and back squat -Twelve men, mean age 25 ±4 years and mean 4 ±1 years training experience	HT had a higher average compared to the back squat (ES = 1.29; p = 0.005) and the lunge (ES = 1.24; p = 0.006), in addition to a higher EMG peak compared to the back squat (ES = 1.08; p = 0.024) and lunge (ES = 1.08; p = 0.016).	n/a	n/a
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HT= Hip thrust; Gmax= gluteus maximus; EMG= Electromyography; BF= Biceps femoris;VL: Vastus lateralis; RM= Maximum repetition; n/a= absence of data; ES= Effect Size.
Source: Author.

4 DISCUSSION

This investigation brings important information about the magnitude of muscular electrical activity stimulated by HT exercises, squats, and their variations. The results of the review indicate that HT exercise elicits higher levels of myoelectric activation for the hip extensor muscles, such as Gmax (Williams *et al.*, 2021; Contreras *et al.*, 2015; Delgado *et al.*, 2019), while the squat seems to favor the activity of the knee extensor muscles (Delgado *et al.*, 2019; McCurdy *et al.*, 2021). For the activation levels of the hamstrings, the results are still inconclusive.

With respect to the levels of EMG activation related to the hamstrings in HT exercises, squats, and their variations, the general results of the studies do not indicate whether any of the exercises are more effective in generating superior myoelectric responses, since, while two of the studies showed no significant differences for the biceps femoris in full repetitions of the exercises (Delgado *et al.*, 2019; McCurdy *et al.*, 2021), another study showed that HT provided greater electrical activity for the biceps femoris compared to the free squat (Contreras *et al.*, 2015).

Some studies have shown that, in relation to the muscle activation of the hamstrings in free squat exercises, the hamstrings present values two to three times lower than the activity of the vastus lateralis or medialis (Contreras *et al.*, 2016; Silva *et al.*, 2017). In multi-joint exercises such as the squat, during the eccentric phase, the hamstrings lengthen in the proximal region of the hip and shorten in the distal region, placing them in a condition of unfavorable length-tension ratio for force production, while the opposite occurs in the concentric phase, a condition known as active insufficiency (Schoenfeld, 2002). In line with this evidence, the work by Kubo *et al.* (2019) investigated the levels of hypertrophic response due to full or partial squat training for eight weeks, and did not observe an increase in hamstring hypertrophy at the end of the

training period. This result seems to be linked to low levels of force production and activation of the hamstrings in these exercises.

On the other hand, although the HT presents the same characteristics of muscle length related to the hamstrings, during the eccentric and concentric phases, there is a distinction regarding the lever arms and torques between the HT and the squats, because, throughout both phases HT tends to present significant resistive torques, mainly in the final phases of the concentric phase, unlike the squat, in which the resistive torque is minimal at the end of the concentric phase.

HT is an exercise in which the body's support base is not functional and this probably requires greater stabilizing activity of the hamstrings, especially when dealing with the use of higher loads, as occurred in the work by Contreras et al. (2015), who used loads of 75% of 1RM, and in the work by McCurdy et al. (2021), who used loads of 80% of 1RM. However, this myoelectric behavior was only observed during the initial third of the movement, not for the final phases, compared to the deep squat.

In the same line of reasoning, the work by Delgado et al (2019), showed that when the EMG activity was compared with loads of 60Kg, which represented an average of approximately 36% of 1RM for HT, there was no electromyographic difference between the exercises. However, when the comparison was made with loads of 1RM, the HT, which presented an average of 164.1Kg for 1RM, demonstrated greater activation of the hamstrings when compared to the other exercises. These results indicate that higher loads may demand greater EMG activity of the hamstrings in HT exercises, however, due to the low number of works that have investigated this issue, further studies are necessary to confirm these proposals.

Considering the results related to the quadriceps, of the four studies, three investigated the vastus lateralis activation, one did not report observation of the quadriceps, and none investigated the action of the rectus femoris. Two studies showed that the squat and its variations induced greater EMG activity of the vastus lateralis than the HT (Delgado *et al.*, 2019; McCurdy *et al.*, 2021). Only one study showed no significant difference in vastus lateralis electromyographic activity between the HT and free squat (Contreras *et al.*, 2015).

In the study of Delgado *et al.* (2019), when the activation of the vastus lateralis was evaluated, the squat had an advantage in the electromyographic tests with 1RM, as well as in the tests with 60 Kg. When McCurdy *et al.* (2021) evaluated the entire repetitions between the exercises, they found a greater advantage for the average values of the Bulgarian squat in relation to the HT. However, the study of Contreras *et al.* (2015) comparing the two previous

studies, revealed that the electromyographic activity for the vastus lateralis did not have a significant difference between the HT compared to the free squat.

During the squat, the rectus femoris goes into active insufficiency and, consequently, requires greater participation of the other quadriceps groups to produce the necessary force to perform knee extension (Ribeiro *et al.*, 2023). On the other hand, in HT the flexed knee together with significant resistive moment arms throughout the entire movement, and particularly the possibility of greater torque production by the rectus femoris when the hip is extended, confer biomechanical characteristics to the HT that may disfavor EMG activation in the vastus due to the greater possibility of force production in the rectus femoris. These characteristics generate an important bias that compromises the comparison of quadriceps activity between the two exercises, HT and squat, which present different biomechanical behaviors regarding quadriceps work.

When analyzing the muscle activity of the Gmax, three studies pointed out that the HT induced greater myoelectric activity compared to the free squat (Delgado *et al.*, 2019; Contreras *et al.*, 2015; Williams *et al.*, 2021). One study showed no significant differences in complete repetitions between exercises (McCurdy *et al.*, 2021), however, this same study showed a difference in EMG activity in the upper third of the movement in favor of HT, while in the lower phase of the movement, the lunge squat showed greater activation of the Gmax. These results may be in line with the demands of muscle torques related to each exercise, as in the upper phases of HT the resistive moment arms are greater for the hip extensors, while in the lower phases of the movement in the lunge squat the resistive moment arms are larger compared to EP, which naturally increases muscle recruitment.

In the study by Delgado *et al.* (2019), HT in the 1RM condition produced greater activity in the Gmax compared to the free squat and also for the 60 Kg condition for both exercises, which demonstrates that even with a lower relative load, the HT provided greater EMG activity in the Gmax compared to the squat, because approximate loads of 36% of the 1RM of the mean of the HT group were below the 42.36% of 1RM of the mean of the free squat.

In the study by Contreras *et al.* (2015), the Gmax also showed greater electrical activity during the HT when compared to the free squat, both for the upper and lower portions of the Gmax. In addition, the study by Williams *et al.* (2021), which evaluated men with experience in all the exercises evaluated, showed that the HT was more efficient in the average activation of the Gmax when compared to the free squat and the lunge squat. Overall, the four studies point out that the HT seems to generate greater EMG activation in the Gmax in the full range

of motion or in the upper third of the movement when compared to the squat or the deep squat, respectively.

5 CONCLUSION

In summary, the results indicate that the HT can provide greater muscle activation in the hip extensors, especially the Gmax, while the squat and its variations seem to induce greater activation in the knee extensors, particularly in the vastus lateralis. However, the results point out some limitations, such as the low number of articles found, small sample size, lack of studies with a more complete analysis by EMG between the muscle groups of the lower limbs, and lack of chronic records related to muscle hypertrophy and neuromuscular activity. Thus, further investigations should be carried out to provide deeper knowledge on this topic.

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