DIFFERENCES IN LOWER LIMB MUSCLE ACTIVITY DURING LUNGE MOVEMENTS IN FENCING ATHLETES WITH AND WITHOUT INJURY HISTORY

ВІДМІННОСТІ В АКТИВНОСТІ М'ЯЗІВ НИЖНІХ КІНЦІВОК ПІД ЧАС ВИКОНАННЯ ВИПАДІВ У СПОРТСМЕНІВ-ФЕХТУВАЛЬНИКІВ ІЗ ТА БЕЗ ТРАВМ В АНАМНЕЗІ

Wisnu Prasetyo Adhi[1], Taufik Eko Susilo[2], Mahendra Wahyu Dewangga[3]
[1,2,3]Department of Physiotherapy, Faculty of Health Sciences, Universitas Muhammadiyah Surakarta, Indonesia
[1]ORCID: 0009-0009-1257-155X
[2]ORCID: 0000-0003-1857-0661
[3]ORCID: 0000-0002-2777-268X

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Abstracts
Purpose the Work: This study aimed to investigate differences in lower limb muscle activity during lunge movements among fencing athletes with and without a history of lower extremity injury, with an emphasis on gender-based variations. Understanding these differences may help refine training and rehabilitation strategies tailored to athlete needs.

Method and Materials: A total of 24 fencing athletes (12 males and 12 females) aged 15–24 years were recruited and categorized into injured and non-injured groups. Surface electromyography (sEMG) was used to measure the activity of seven lower limb muscles – rectus femoris, vastus medialis, vastus lateralis, biceps femoris, semitendinosus, gastrocnemius medialis, and gastrocnemius lateralis – during lunge movements. Muscle activity data were analyzed using independent t-tests via SPSS version 26.

Results: In male athletes, significantly higher muscle activity was observed in the non-injured group for the rectus femoris, vastus medialis, vastus lateralis, and gastrocnemius lateralis ($p < 0.05$). In contrast, female athletes with no injury history showed significantly greater muscle activation in the rectus femoris, vastus medialis, vastus lateralis, biceps femoris, semitendinosus, and gastrocnemius medialis ($p < 0.05$). Some muscle groups, such as the biceps femoris and semitendinosus in males and the gastrocnemius lateralis in females, did not differ significantly between groups.

Conclusion: Lower extremity injuries result in reduced muscle activity during lunge movements, with broader effects observed in female athletes. These findings underscore the importance of considering gender differences in the development of injury prevention and rehabilitation programs for fencing athletes.
Key words: Electromyography, Muscle Activity, Lower Limb Injury, Gender Differences, Rehabilitation.

Мета роботи: Це дослідження мало на меті дослідити відмінності в активності м'язів нижніх кінцівок під час випадів у фехтувальників із травмами нижніх кінцівок та без них з акцентом на гендерні відмінності. Розуміння цих відмінностей може допомогти вдосконалити стратегії тренувань та реабілітації, адаптовані до потреб спортсменів.

Методи та матеріали: Загалом було набрано 24 фехтувальники (12 чоловіків та 12 жінок) віком 15–24 років, яких було розділено на групи з травмами та без них. Для вимірювання активності семи м'язів нижніх кінцівок: прямого м'яза стегна, медіального широкого м'яза стегна, латерального широкого м'яза стегна, двоголового м'яза стегна, напівсухожильного м'яза, медіального литкового м'яза та латерального литкового м'яза під час випадів було використано поверхневу електроміографію (сЕМГ). Дані про м'язову активність проаналізовано за допомогою незалежних t-тестів у SPSS версії 26.

Результати: У спортсменів-чоловіків у групі без травм спостерігалася значно вища м'язова активність прямого м'яза стегна, медіального широкого м'яза стегна, латерального широкого м'яза та латерального литкового м'яза ($p < 0,05$). Натомість спортсменки без травм у анамнезі показали значно більшу м'язову активацію прямого м'яза стегна, медіального широкого м'яза стегна, латерального широкого м'яза стегна, напівсухожильного м'яза стегна та медіального литкового м'яза ($p < 0{,}05$). Деякі групи м'язів, такі як двоголовий м'яз стегна та напівсухожильний м'яз у чоловіків та латеральний литковий м'яз у жінок, суттєво не відрізнялися між групами.

Висновок: Травми нижніх кінцівок призводять до зниження м'язової активності під час випадів, причому ширші наслідки спостерігаються у спортсменок. Ці результати підкреслюють важливість урахування гендерних відмінностей у розробленні програм профілактики травм та реабілітації для спортсменів-фехтувальників.

Ключові слова: електроміографія, м'язова активність, травми нижніх кінцівок, гендерні відмінності, реабілітація.

Introduction. Fencing is a sport with a long-standing history and is considered prestigious in many countries. Over time, it has evolved into a recognized Olympic discipline and continues to undergo innovations in both technique and training methods [19]. Modern fencing originated as a competitive sport in Europe and has since gained global recognition, with over 150 member federations across various nations [4]. As a sport that demands speed, precision, and strategy, fencing is classified as a high-skill or dexterity-based sport [18]. Fencers must be able to rapidly change direction and maintain body balance during dynamic movements involving both offensive and defensive actions. To support these demands, good neuromuscular control is essential to ensure efficient and effective movement execution [9].

One of the fundamental techniques in fencing is the lunge, which requires coordination between the upper and lower body [5]. This movement activates the kinetic chain involving the ankles, knees, and hips to propel the blade toward the opponent [2]. Footwork during the lunge consists of forward or backward movement to attack or maintain distance. Each foot plays a distinct role: the non-dominant leg functions as a propulsive force through concentric contractions of the knee extensors and triceps surae, while the dominant leg provides stability and movement control via eccentric contractions [11].

Research has shown that quadriceps strength plays a crucial role in performing efficient lunge movements due to the interdependence between knee and ankle joint control [18]. Despite being vital for competitive performance, the lunge movement is also associated with a high risk of lower extremity injuries, particularly in the knees, thighs, and ankles [24]. An epidemiological study on professional fencing athletes in South Korea reported that 47.2% of injuries occurred in the lower limbs, with the knee being the most frequently affected joint [21]. Given its role as the primary stabilizer, the knee is more vulnerable to stress and injury than other joints [1].

The lunge involves intense muscular contractions, and skeletal muscle accounts for approximately 45% of total body mass. Excessive mechanical load can lead to muscle injuries such as bruising, strain, or tearing. Alekseyev et al. (2016) found that fencers with high training loads frequently sustained injuries to the hamstring, quadriceps, and gastrocnemius muscles. Among the different types of contractions, eccentric contractions have been reported to cause more frequent injuries compared to concentric or isometric types [17]. Therefore, this study focuses on muscle contraction as a variable to assess muscle activity during the lunge movement in fencing athletes.

Muscle activity in this study will be evaluated using Surface Electromyography (sEMG), a non-invasive method that provides objective, real-time analysis of muscle activation. It is widely used as a standard tool to assess muscle function during physical activity [20]. The use of sEMG in this study aims to collect accurate data on muscle contractions under varying conditions and intensities. Additionally, sEMG analysis can assist clinicians in understanding how muscular dysfunctions relate to physical impairments. By analyzing muscle activation patterns during the lunge, this study aims to offer new insights into injury prevention and training optimization for fencers.

Several previous studies have examined injuries in fencing athletes but with differing focuses. For instance, Thompson explored injury epidemiology among U.S. national and Olympic fencers without assessing muscle activity [24]. Some studied injury prevalence among Korean fencers, highlighting factors such as age, gender, and experience, and found the ankle to be the most commonly injured area [6]. Some research reported that patellofemoral extensor dysfunction was the most frequent injury but did not investigate muscle activity [7]. Similarly, Swatowska identified the lower limbs as the most injury-prone area without differentiating by gender or recording muscle activity [23]. Santoso (2023) examined the effect of knee pain on balance and quadriceps electromyography activity during the lunge but did not compare athletes with and without prior injury [22]. Meanwhile, some study from harmer focused on injury epidemiology during international competitions and risk factors related to gender and fencing discipline, again without exploring muscle function [15].

Given these research gaps, the present study aims to identify differences in lower limb muscle activity during the lunge movement in fencers with and without a history of injury. To achieve this, muscle contraction data will be collected from key lower limb muscles: the rectus femoris, vastus medialis, vastus lateralis, biceps femoris, semitendinosus, gastrocnemius medialis, and gastrocnemius lateralis. This approach is expected to reveal more specific activation patterns and provide insight into how these muscles contribute to stability and power during fencing lunges.

Moreover, this study is expected to offer both theoretical and practical contributions. Theoretically, it will enhance the understanding of muscle contraction mechanisms during the lunge, particularly in athletes with previous injuries. Practically, the findings could be used to inform the design of more effective training and rehabilitation programs aimed at improving performance and preventing injuries in fencing athletes.

Method Research. Design and Participant. The population for this study consists of fencing athletes (both male and female) who compete at the regional or national level, regardless of their history of lower limb injuries. Sample size determination was conducted using quota sampling, where quotas for each relevant category in the population were set, and samples were selected accordingly. The final sample included 24 individuals: six uninjured males, six injured males, six uninjured females, and six injured females. Inclusion criteria required athletes to be between the ages of 15 and 24, have more than two years of experience, be of either gender, and have or have not experienced lower extremity injuries. Additionally, participants needed to agree to participate by signing an informed consent form. Exclusion criteria included athletes who were absent during testing and measurement sessions or who declined to participate.

Ethical Considerations. The research received approval from the Health Sciences Research Ethics Committee of the Faculty of Health Sciences, Muhammadiyah University of Surakarta, Central Java, under approval number No. 620/KEPK-FIK/X/2024. Prior to the commencement of the study, all participants provided written informed consent after reviewing the experimental methods.

Data Collection Method. Data collection took place at the Sport Hall Universitas Tunas Pembangunan Surakarta from January to February 2025. The study variables include independent variables (gender and injury history) and dependent variables (lower extremity muscle activity, measured using the Surface EMG Noraxon 3.8.30 myoMetrics on the rectus femoris, vastus medialis, vastus lateralis, biceps femoris, semitendinosus, gastrocnemius medialis, and gastrocnemius lateralis muscles during the lunge movement).

Before the study began, participants completed a questionnaire containing their personal information, including age, height, weight, and body mass index (BMI). BMI was calculated using the formula kg/m², and the resulting data was used as supplementary information for the research.

The second measurement involves assessing the activity of the lower extremity muscles using

Table 1

Body Mass Index

Category	Score
Underweight	< 18,5
Normal	18,5 – 25
Over Weight	25 – 30
Obesity	>30

surface electromyography (sEMG) on the rectus femoris, vastus medialis, vastus lateralis, biceps femoris, semitendinosus, gastrocnemius medialis, and gastrocnemius lateralis muscles during a lunge movement. Surface electromyography (sEMG) is highly valid for measuring lower extremity muscle activity, with a strong correlation to torque (TA: $\rho > 0.92$; SOL: $\rho > 0.94$) and high reliability (ICCmean = 0.90; range 0.72-0.99) (Silverman et al., 2021).

Before data recording, participants were instructed to warm up. The examiner then attaches EMG electrodes to the rectus femoris, vastus medialis, vastus lateralis, biceps femoris, semitendinosus, medial gastrocnemius, and lateral gastrocnemius muscles. Participants were asked to remain still and step forward as if sparring with their friends. Each participant completed three sets of lunges, which were recorded using the EMG to ensure comprehensive data collection.

Result. Data Analysis. Data analysis was performed using bivariate tests in SPSS, starting with a normality test using the Shapiro-Wilk test. If the data is normally distributed, a parametric independent t-test is applied to compare the average muscle activity between groups. If the data is not normally distributed, a non-parametric Mann-Whitney U test is used instead. This approach ensures accurate comparisons between the groups based on their distribution characteristics. This study involved a total of 24 participants, with an equal distribution based on gender: 12 males (50%) and 12 females (50%). This balanced gender distribution allows for a more objective analysis of various factors influencing health status and injury occurrences within the studied population. The age distribution of the participants shows that the largest group falls within the 15–17 year age range, consisting of 10 individuals (41.67%). The other age groups are smaller, with the 17–20 year age group comprising 5 individuals (20.83%) and the 20–24 year age group consisting of 9 individuals (37.5%).

Body Mass Index (BMI) is an important parameter for assessing an individual's nutritional status and health risks. In this study, the majority of participants had a BMI within the normal category, with 16 individuals (66.67%). Meanwhile, 6 individuals (25%) were categorized as underweight, which may indicate factors such as insufficient nutrient intake, high levels of physical activity, or other metabolic factors. Additionally, 2 individuals (8.33%) fell into the overweight category, which, though relatively small in number, remains an important factor for long-term health analysis. No participants were classified as obese (0%). The absence of obesity in the sample may be attributed to factors such as high levels of physical activity, maintained dietary habits, or participant selection criteria.

Table 2

Sample Population

	Category	Frequency	Percentage
Sex	Male Female Total	12 12 24	50% 50% 100%
Age/class	15 – 17 17 – 20 20 – 24 Total	10 5 9 24	41,67% 20,83% 37,5% 100%
BMI	Underweight Normal Overweight Obesity Total	6 16 2 0 24	25% 66,67% 8,33% 0 % 100%
Injury	Lower limb injury (Man) (Woman) No Lower limb injury (Man) (Woman) Total	 6 6 6 6 24	 25% 25% 25% 25% 100%

Lower extremity injuries are a common issue, especially among individuals who are physically active or involved in sports activities. Of the 24 participants, 12 individuals (50%) had experienced lower extremity injuries, while the remaining 12 individuals (50%) had not. The injury distribution by gender was balanced, with 6 males (25%) and 6 females (25%) reporting injuries. Similarly, among the group that did not experience injuries, 6 males (25%) and 6 females (25%) were injury-free.

After measurements were taken using surface electromyography (sEMG) on the rectus femoris, vastus medialis, vastus lateralis, biceps femoris, semitendinosus, gastrocnemius medialis, and gastrocnemius lateralis muscles during the lunge movement in both males and females, the following results were obtained.

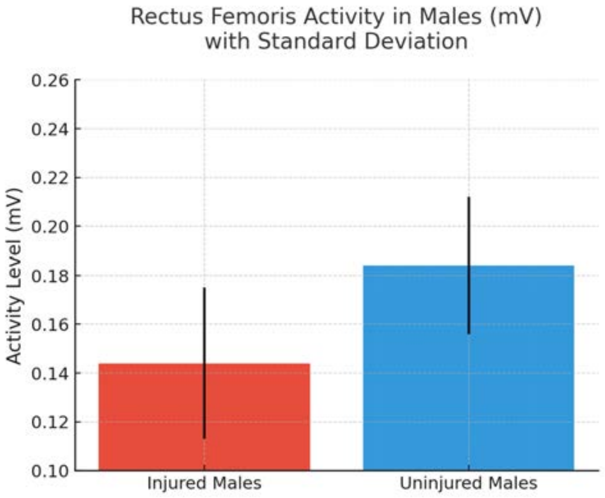

Fig. 1. Electromyographic Activity Rectus Femoris Muscle

From the measurement results using the method described, it is evident that the group of injured males shows lower Rectus Femoris activity compared to the group of uninjured males. Quantitatively, the average muscle activity value in the injured group is around 0.14 mV, while the non-injured group shows a higher activity value, around 0.18 mV. A statistical analysis using SPSS revealed a significant difference between the two groups ($p < 0.05$), confirming that the lower muscle activity in the injured group is statistically meaningful.

The activity of the Vastus Medialis in the male group also decreased in the injured group compared to the uninjured group. The average muscle activity in the injured group was around 0.12 mV, while in the uninjured group, it reached 0.18 mV. Statistical analysis using SPSS revealed a significant difference between the two groups ($p < 0.05$), indicating that the decreased muscle activity in the injured group is statistically significant.

The analysis results show that the activity of the Vastus Lateralis muscle in the injured male group is lower compared to the uninjured group. The average muscle electrical activity (electromyography, EMG) in the injured group is around 0.13 mV, while in the uninjured group, it is higher, reaching approximately 0.17 mV. Statistical analysis using SPSS indicated a significant difference between the two groups ($p < 0.05$), confirming that the lower muscle activity in the injured group is statistically significant.

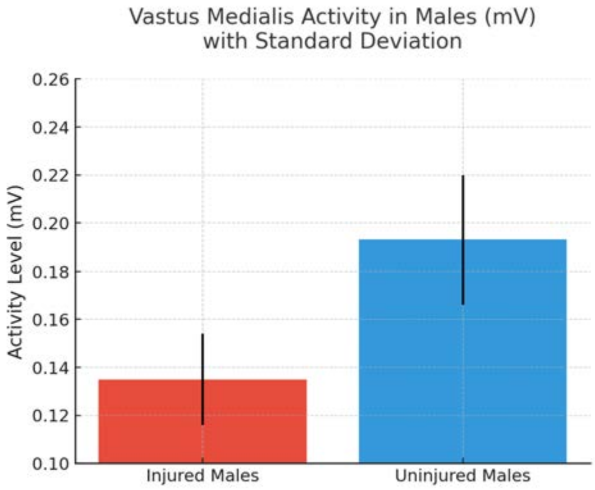

Fig. 2. Electromyographic Activity Vastus Medialis Muscle

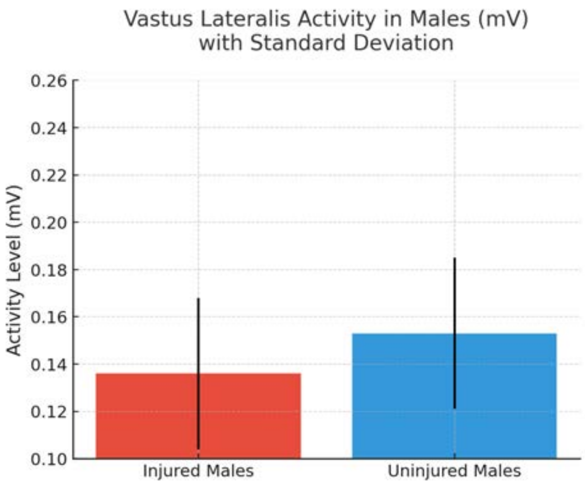

Fig. 3. Electromyographic Activity Vastus Lateralis Muscle

The activity of the Biceps Femoris muscle shows a pattern where the injured male group exhibits higher muscle activity, with an average value of 0.19 mV, compared to the uninjured group, which shows an average of 0.17 mV. Statistical analysis using SPSS revealed no significant difference between the two groups (p > 0.05), suggesting that the observed difference in muscle activity is not statistically significant.

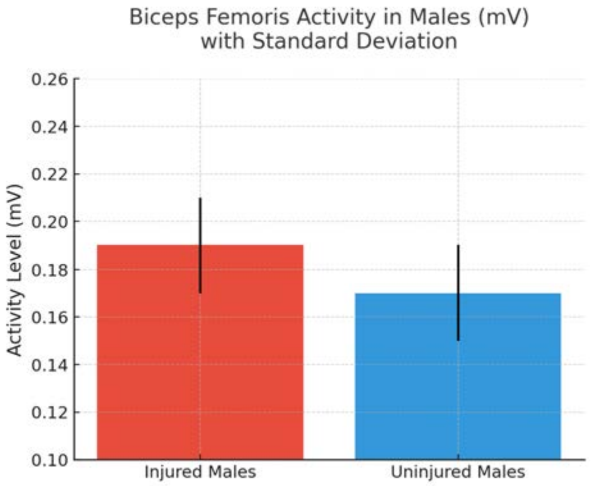

Fig. 4. Electromyographic Activity Biceps Femoris Muscle

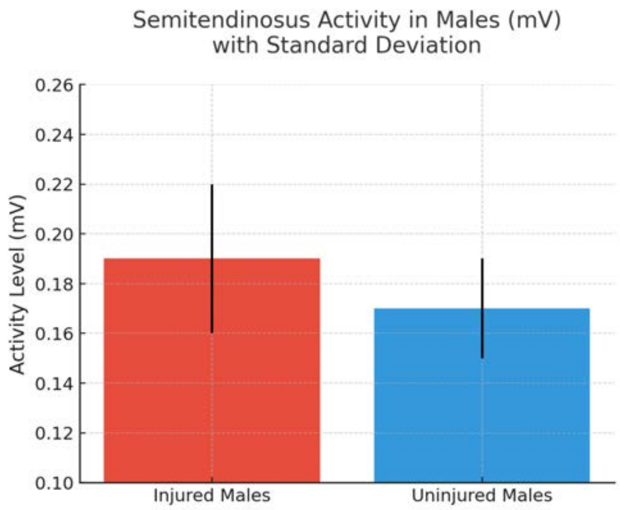

Fig. 5. Electromyographic Activity Semitendinosus Muscle

Meanwhile, the results for the Semitendinosus muscle in the male group showed a trend similar to that of the Biceps Femoris. The average muscle activity in the injured group was higher at 0.19 mV, compared to the non-injured group, which showed an average of 0.17 mV. Statistical analysis using SPSS revealed no significant difference between the two groups (p > 0.05), indicating that the observed difference in muscle activity is not statistically significant.

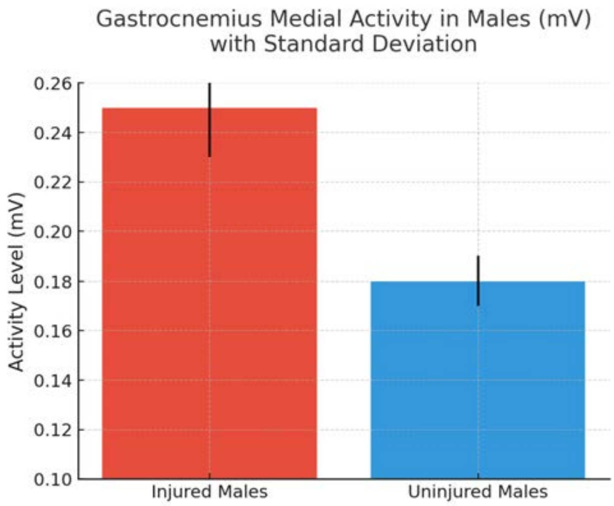

Fig. 6. Electromyographic Activity Gastrocnemius Medialis Muscle

The analysis results revealed a significant difference in the activity of the medial gastrocnemius muscle between the two male groups. The injured group demonstrated a higher average muscle activity of 0.25 mV, compared to 0.18 mV in the uninjured group. Statistical analysis confirmed this difference to be significant (p < 0.05), suggesting that injury status may influence increased activation of the medial gastrocnemius during the lunge movement.

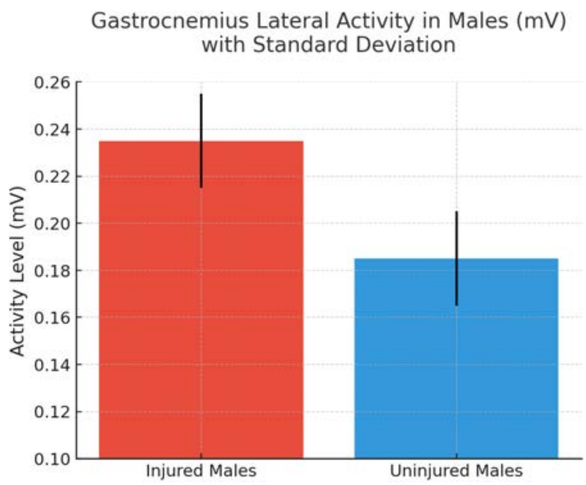

Fig. 7. Electromyographic Activity Gastrocnemius Lateralis Muscle

A similar trend was observed in the lateral gastrocnemius muscle, where the injured male group exhibited higher muscle activity, averaging 0.23 mV, compared to 0.18 mV in the uninjured male group. This increase suggests a possible compensatory mechanism in response to injury, although statistical analysis would be needed to determine the significance of this difference.

Meanwhile, the measurement results for the female fencing athlete group using surface electromyography or sEMG were as follows.

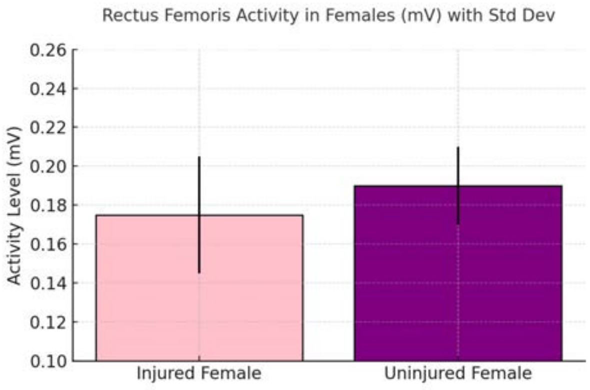

Fig. 8. Electromyographic Activity Rectus Femoris Muscle

The results indicate that the injured female group had a slightly lower average Rectus Femoris muscle activity of 0.17 mV compared to 0.18 mV in the uninjured female group. Although this difference appears minimal, statistical analysis showed that it was not significant ($p > 0.05$), suggesting that Rectus Femoris activation during the lunge movement was relatively similar between injured and uninjured female athletes.

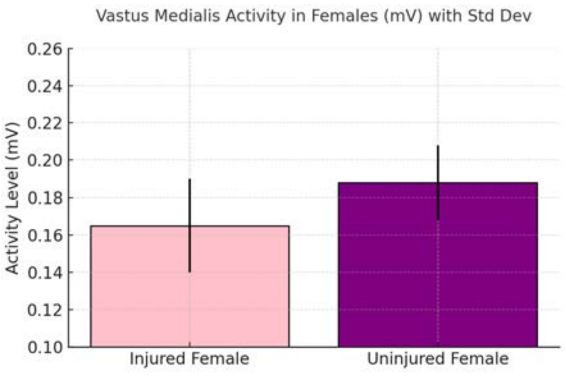

Fig. 9. Electromyographic Activity Vastus Medialis Muscle

In the group of women with injuries, the average Vastus Medialis muscle activity was 0.19 mV, while the group of women without injuries showed a slightly lower value of 0.17 mV. However, this difference was not statistically significant ($p > 0.05$), indicating that injury status did not markedly affect Vastus Medialis activation in female participants during the lunge movement.

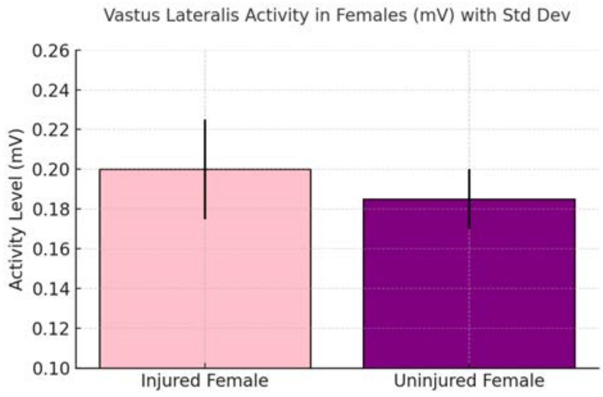

Fig. 10. Electromyographic Activity Vastus Lateralis Muscle

Meanwhile, the group of women with injuries had an average Vastus Lateralis muscle activity of 0.20 mV, compared to 0.18 mV in the group of women without injuries. However, this difference was not statistically significant ($p > 0.05$), suggesting minimal impact of injury status on Vastus Lateralis activation in female participants during the lunge movement.

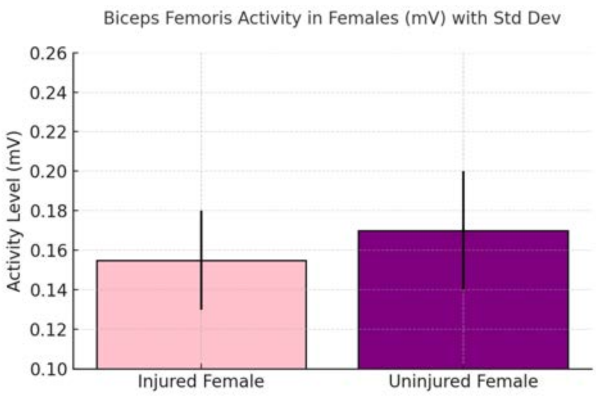

Fig. 11. Electromyographic Activity Biceps Femoris Muscle

From the displayed results, the average electromyographic activity of the Biceps Femoris muscle in the injured female group was recorded at 0.15 mV, while in the uninjured group it was higher, at 0.17 mV. However, this difference was not statistically significant ($p > 0.05$), suggesting that injury status did not notably affect Biceps Femoris activation in female participants during the lunge movement.

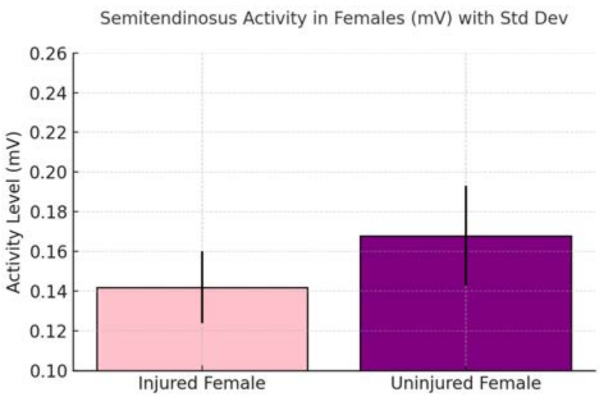

Fig. 12. Electromyographic Activity Semitendinosus Muscle

The results shown in the graph indicate that the average Semitendinosus muscle activity in injured women is around 0.14 mV, while the non-injured group shows a higher value of 0.16 mV. However, this difference was not statistically significant ($p > 0.05$), suggesting that injury status had minimal impact on Semitendinosus muscle activation during the lunge movement in female participants.

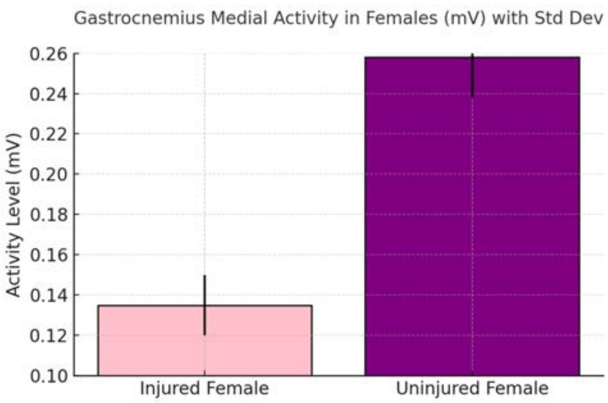

Fig. 13. Electromyographic Activity Gastrocnemius Medial Muscle

From the graph, it can be seen that the Gastrocnemius Medialis muscle activity in uninjured women is significantly higher compared to injured women. The average muscle activity in the uninjured group reached 0.26 mV, while in the injured group it was only around 0.14 mV. This difference was statistically significant ($p < 0.05$), suggesting that injury status notably affects Gastrocnemius Medialis activation during the lunge movement in female participants.

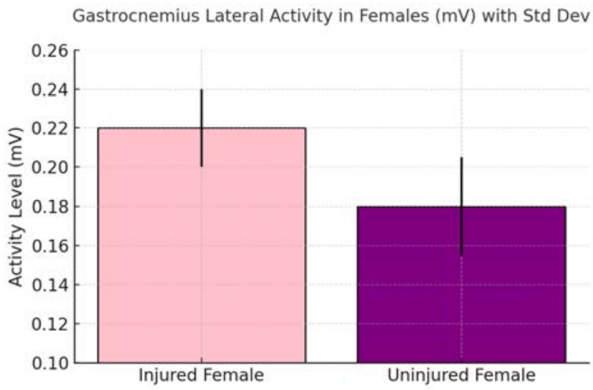

Fig. 14. Electromyographic Activity Gastrocnemius Lateralis Muscle

The last measurement was on the Gastrocnemius Lateralis muscle in the female group, where the average muscle activity for injured women was around 0.21 mV, while the non-injured group exhibited a lower value of 0.18 mV. However, this difference was not statistically significant ($p > 0.05$), indicating that injury status had minimal effect on Gastrocnemius Lateralis muscle activation during the lunge movement in female participants.

Discussion. The results of measuring lower limb muscle activity using surface electromyography (sEMG) revealed substantial variations in muscle activity between male and female groups, both injured and non-injured. In general, the non-injured group showed higher muscle activity compared to the injured group, which suggests that injury can negatively impact muscle performance during functional movements like lunges. This aligns with findings from previous studies that suggest muscle activity decreases after injury due to impaired neuromuscular function [12].

In the male group with a history of injury, muscle activity was significantly lower than in the non-injured group. Specifically, the rectus femoris, vastus medialis, and vastus lateralis muscles showed considerable reductions in activity. These findings are consistent with previous research that found diminished muscle activation in individuals recovering from injuries [12]. The lateral and medial gastrocnemius muscles also exhibited significant differences, indicating a generalized reduction in neuromuscular function. This decrease in activity could be attributed to disruptions in the muscle's ability to contract optimally due to injury-related alterations in the neuromuscular system [16].

Interestingly, the female group with a history of injury displayed a more varied pattern of muscle activity. In some muscles, such as the vastus medialis and vastus lateralis, there was higher activity compared to the non-injured group. This suggests the presence of a compensatory mechanism, where certain muscles are activated more to compensate for deficits in others caused by the injury. This compensation mechanism has been reported in other studies, which indicate that individuals with injuries often rely on alternative muscle groups to perform movements [13].

In statistical analysis, the t-test results showed that in the male data, muscle activity distributions between the injured and non-injured groups were generally similar, with no significant differences in most muscles. However, specific muscles such as the rectus femoris, vastus medialis, vastus lateralis, and lateral gastrocnemius showed significant differences, which indicates that these muscles may have been particularly affected by the injury. This is in line with research by Sinclair and Bottoms, which found that injuries lead to reduced muscle activity in certain regions, potentially causing biomechanical issues during dynamic activities [14].

On the other hand, muscles like the biceps femoris, semitendinosus, and gastrocnemius medialis showed no significant differences between the injured and non-injured groups. This could suggest that these muscles were either less affected by the injury or underwent adaptations that allowed for a faster recovery compared to other muscles. Some research also found that certain muscles recover more efficiently due to compensatory adaptations in muscle recruitment patterns following injury [25, 26]. Additionally, studies by Thomas have shown that rehabilitation interventions can significantly improve muscle function, especially in muscles that recover more slowly [10].

This study's findings are consistent with previous research exploring the impact of injury on lower extremity muscle activity. For instance, Fournier found that individuals with knee injuries demonstrated decreased quadriceps activity, which correlates with our findings that the rectus femoris and vastus medialis exhibited significantly lower activity in the male injured group [12]. Furthermore, Ji concluded that injury-related neuromuscular dysfunction affects muscle contraction optimization, which was evident in our data showing reduced muscle activity in injured groups [16].

However, the female group demonstrated a more pronounced compensatory response, especially in muscles like the vastus medialis and vastus lateralis. This compensatory mechanism is in contrast to the findings of Klarod and Surakul, who suggested that women with a history of injury tend to exhibit greater deficits in muscle activation than men [17]. Our study suggests that the increased muscle activity in the injured women might be related to biomechanical adaptations, such as greater stiffness in the lower limbs [21].

The compensatory response observed in women could also be influenced by hormonal and biomechanical factors. Some research suggests that female athletes may exhibit greater biomechanical adaptations, such as increased hip and knee stiffness, which might help compensate for muscle deficits and prevent injury [8]. This theory is supported, which indicated that female athletes tend to have higher stiffness in the lower extremities compared to males, which may enhance load distribution during dynamic tasks [27].

In terms of rehabilitation and injury prevention, the results of this study emphasize the importance of targeted rehabilitation programs for both male and female athletes recovering from lower extremity injuries. Although muscle recovery can vary across different muscle groups and genders, it is essential to develop personalized rehabilitation strategies to address the specific needs of individuals [3]. Moreover, preventing injuries through proper training techniques and exercise regimens can help maintain muscle activity and prevent long-term biomechanical disturbances.

This study also opens avenues for future research to further investigate gender differences in muscle activity following injury. There is a need for more studies to explore the mechanisms behind compensatory muscle activation and how biomechanical adaptations differ between genders. Additionally, it is important to examine the effects of various rehabilitation interventions on muscle recovery in injured individuals, particularly focusing on strengthening the weaker muscle groups that are most affected by injury.

Conclusions. Based on the research findings, it can be concluded that injuries have a significant impact on the activity of lower extremity muscles, particularly the quadriceps and gastrocnemius muscles. The group of men with a history of injury showed a more significant decrease in muscle activity compared to the non-injured group, highlighting the detrimental effect injuries have on muscle function. In contrast, the group of women with a history of injury exhibited a compensatory pattern, where certain muscles were activated more to make up for the deficits caused by the injury. This indicates that injury-related changes not only affect muscle activity but also have long-term implications for functional performance and mobility.

As a preventive measure, it is crucial to implement training programs that focus on enhancing joint stability and muscle strength to reduce the risk of injury, particularly for individuals who engage in high-impact sports or physically demanding activities. Post-injury rehabilitation should be carefully tailored to address the specific muscle activity patterns affected by the injury, ensuring optimal recovery. Given the observed differences between male and female responses to injury, further studies are recommended to investigate the most effective rehabilitation strategies, considering the unique biomechanical and neuromuscular differences in each gender. By gaining a deeper understanding of these patterns, prevention and rehabilitation programs can be better designed to enhance the quality of life and functional performance of individuals recovering from injuries.

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