

Response of eccentric exercise, proprioceptive neuromuscular facilitation, and flexibility on delayed onset muscle soreness induced by progressive eccentric training

ILHAM^{1*}, IIT SELVIANI², FIRDA AZZAHRA³, FADILLAH TERESSA⁴, MULIYA SAFITRI⁵, BEKIR ERHAN ORHAN⁶, VLAD ADRIAN GEANTĂ⁷

^{1,2,4,5}Department of Health and Recreation, Faculty of Sports Science, Universitas Negeri Padang, INDONESIA

²Department of Physical Education, Faculty of Sports Science, Universitas Negeri Padang, INDONESIA

⁶Faculty of Sports Sciences, Istanbul Aydın University, Istanbul, TURKIYE

⁷Doctoral School of Sport Science and Physical Education, National University of Science and Technology Polyethnic Bucharest - Pitesti University Center, ROMANIA

⁷Aurel Vlaicu University of Arad, Faculty of Physical Education and Sport, ROMANIA

Published online: December 30, 2024

Accepted for publication: December 15, 2024

DOI:10.7752/jpes.2024.12322

Abstract:

Background: Delayed onset muscle soreness (DOMS) refers to micro-injuries in skeletal muscle fibers resulting from excessive mechanical stress during exercise. This leads to inflammation of the muscles, resulting in pain and stiffness. **Purpose:** This study aims to investigate (1) the differences between eccentric exercise and proprioceptive neuromuscular facilitation (PNF) stretching regarding flexibility levels and their effects on pain reduction in DOMS; (2) the differences in pain reduction between individuals with high versus low flexibility levels; and (3) the interaction between exercise therapy methods (eccentric exercise and PNF) and flexibility levels on pain reduction in DOMS. **Methods:** A quasi-experimental design was adopted, and a two-way analysis of variance (ANOVA) was used. The study recruited participants via purposive sampling, where diverse features defined the inclusion criterion and provided written consent for all research phases. Sixty male participants were divided into four groups: A1B1, A1B2, A2B1, and A2B2. Data were analyzed using descriptive and inferential statistics (hypothesis testing) through Microsoft Excel, Origin Pro 18, and SPSS 25. DOMS was induced, and treatment sessions were delivered in five sets per session at 24, 48, and 72 hours over a week. Pain intensity was evaluated using the Visual Analog Scale (VAS). **Results:** 1) The results showed that DOMS pain had reduced more with eccentric exercise than PNF with an F-interaction value of 96.494, the p-value, (0.000) < 0.05 significance level. The mean pain reduction score in eccentric exercise was 6.30, while that recorded for the PNF group was 4.10. 2) There were also significant differences in pain reduction between high and low flexibility levels, as indicated by an F-value (F_inter_B) of 25.608 with a p-value of 0.000 (p < 0.05). The mean pain reduction in individuals with high flexibility was 5.77, compared to 4.63 for those with low flexibility. 3) A significant interaction was found between exercise therapy methods and flexibility levels in reducing muscle soreness, with an interaction F-value (F_inter_AB) of 12.759 and a p-value of 0.001 (p < 0.05). **Conclusion:** These results demonstrate that eccentric exercise is more effective in reducing DOMS pain than PNF stretching. Additionally, individuals with higher flexibility levels experience more significant pain reduction compared to those with lower flexibility. The results obtained in this study show a therapeutic exercise that trainers and physical therapists can use.

Keywords: delayed onset muscle soreness, eccentric, proprioceptive neuromuscular facilitation stretching, flexibility, progressive load

Introduction

The response to high-volume, progressively loaded eccentric training typically damages skeletal muscles and connective tissues, particularly in untrained individuals. This response is commonly known as Delayed Onset Muscle Soreness (DOMS), characterized by muscle pain that begins 6–8 hours after exercise, peaks between 24–48 hours, and may persist for up to one week (De Oliveira et al., 2023; Hody et al., 2019; Mizumura & Taguchi, 2024; Wackerhage, 2003). DOMS is accompanied by decreased strength, range of motion (ROM), and muscle function. Traditionally, the mechanism of DOMS was related to lactic acid accumulation. As a byproduct of glycolysis, lactate has been shown to induce pain when injected into skeletal muscle (Gregory et al., 2015; Keriven et al., 2023; Peterson et al., 2020).

During DOMS, pain is intensified by palpation of the affected muscle or tendon. Additionally, the muscle temporarily loses its ability to achieve maximal contraction after exercise, with gradual recovery over time (Tenberg et al., 2022; Wilke & Behringer, 2021). An illustration of DOMS occurrence is shown in Figure 1.

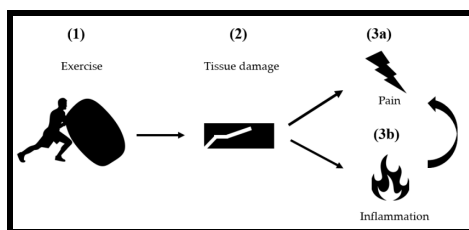


Figure 1. The schematic model of the origin of fascial DOMS: intense physical exercise (1), morphological damage occurs in the extramuscular connective tissue (2), stimulating algogenic free nerve endings (3a). Concurrently, local inflammation, increased edema, and swelling exacerbate the pain response (Wilke & Behringer, 2021).

Generally, DOMS symptoms arise from the mechanical stress exerted on muscle fibers during exercise, disrupting sarcomeres—the fundamental units of muscle contraction (Menezes et al., 2022). This disruption subsequently affects calcium homeostasis in the form of damaging the sarcoplasmic reticulum, the calcium storage site in muscle cells. Elevated intracellular calcium levels further exacerbate muscle damage and impair recovery (Ambardini & Kushartanti, 2024; Nahon et al., 2021). Additionally, the inflammatory response to muscle fiber damage results in fluid accumulation within the injured tissue, leading to swelling. Neutrophils and macrophages migrate to the site of inflammation, playing a dual role in both the damage and repair processes (Proske & Morgan, 2001).

DOMS presents a significant concern, particularly for untrained individuals beginning physical exercise. It acts as a barrier, discouraging the individuals from continuing the activity. Those who have DOMS suffer microtrauma associated with DOMS, such as muscle weakness, pain, reduced range of motion (ROM), and increased muscle tension. These symptoms can increase the risk of further sports-related injuries. For instance, if individuals persist in physical activity despite DOMS symptoms, their limited mobility and potential loss of stability may increase the risk of injury.

Various strategies have been explored to mitigate DOMS-related pain. For instance, several interventions, such as static stretching, passive stretching, proprioceptive neuromuscular facilitation (PNF), and massage, have shown promising results (Alsultan et al., 2020; Menezes et al., 2022). Unfortunately, strategies for accelerating recovery from DOMS remain under investigation. Among the more researched approaches are exercises that target muscle contraction characteristics, particularly eccentric contractions (Martinez-Gago et al., 2024). There are three main types of muscle contractions: concentric, eccentric, and isometric (Benford et al., 2021; Tomalka, 2023). Of the three types, DOMS is often associated with eccentric contractions, where the muscle lengthens under tension (Gokce et al., 2019; Hody et al., 2019; Kisner & Colby, 2007). For example, during the lowering phase of a deadlift, the muscle undergoes eccentric contraction (Akl, 2013; Ilham et al., 2024; Muanjai et al., 2022; Sabouri et al., 2022; Živanović, 2022). To address DOMS, submaximal eccentric contraction training sessions are recommended, gradually increasing intensity throughout the training (Hody et al., 2019). These muscles have unique characteristics that lead to distinct physiological adaptations compared to other contractions (Bompa & Buzzichelli, 2015; Kisner & Colby, 2007). Therefore, exercises incorporating eccentric contractions are often used in rehabilitation or recovery programs.

Exercises incorporating eccentric contractions are often used in rehabilitation or recovery programs. Eccentric training stimulates adaptations that enhance muscle tolerance to stress and reduce exercise-induced muscle damage (Boesen et al., 2017; Breda et al., 2020; Cannell et al., 2001; Monajati et al., 2016; Wackerhage, 2003; Živanović, 2022). While DOMS is typically caused by unusual or intensive exercise, exercise itself, when applied systematically, can also effectively reduce DOMS symptoms (Kancherla, 2023). The focus of such exercises should be on engaging supporting muscles while avoiding the sore muscles to prevent further damage (Nahon et al., 2021). Another commonly recommended method for alleviating DOMS-related pain is stretching. The underlying theory suggests that muscle soreness from progressive load eccentric training can lead to muscle spasms, which reduce blood flow. Stretching can help restore circulation by breaking the pain-spasm-pain cycle (Baxter et al., 2017). Additionally, an individual's flexibility level has been shown to influence the severity of DOMS experienced after exercise. Several studies have reported a correlation between muscle flexibility and DOMS severity (Rizqi & Ambardini, 2019; Tenberg et al., 2022; Zulaini et al., 2021).

Stretching techniques, including static stretching, dynamic stretching, and proprioceptive neuromuscular facilitation (PNF), are commonly employed to manage DOMS (Khodayari & Dehghani, 2012). However, recent studies showed that these protocols did not significantly impact explosive force and jump resistance in sports like basketball (De Oliveira Júnior et al., 2018; Papadimitriou et al., 2017; Vancini et al., 2014). In this context, it is important to consider that passive mobilization and PNF techniques are utilized not only in rehabilitation (Gashi et al., 2023) or conditions like cervical radiculopathy but also in sports settings to enhance performance and recovery. Similarly, a study involving 23 swimmers aged 12 to 15 found that PNF did not enhance leg mobility or performance compared to a control group (Papadimitriou et al., 2017). These findings suggest that, although warm-up exercises often include stretching, the acute effects of PNF on performance metrics may be limited in both swimming and basketball contexts.

The effects of eccentric exercise on DOMS have been linked to several mechanisms, including muscle remodeling, enhanced protection against future damage, and improved blood flow (Burgos-Jara et al., 2023; Hody et al., 2019; Paulsen et al., 2012). One of the most discussed effects is its ability to elevate the activity of anti-inflammatory enzymes and reduce the excessive inflammatory response associated with DOMS (Fatouros & Jamurtas, 2016; Peake et al., 2017). Additionally, several studies have reported that proprioceptive neuromuscular facilitation (PNF) stretching is an effective method for recovering from DOMS (Afonso et al., 2021; Eken & Bayer, 2022; Kommers et al., 2024; Sohail et al., 2019; Warneke et al., 2024). Research involving hold-relax with agonist contraction (HR-AC) following intensive eccentric exercise of the non-dominant biceps brachii has shown that regular HR-AC sessions significantly reduce muscle soreness and improve range of motion (ROM) after 72 hours ($p < 0.05$) (Cha & Kim, 2015). Similarly, studies on the HR-AC technique in the hamstring muscle have demonstrated significant improvements in muscle activity and decreased muscle fatigue, supporting its effectiveness in managing DOMS (Cha & Kim, 2015).

Up to the present, a comparison of dynamic and static stretching techniques has shown that dynamic oscillatory stretches are more effective in improving hamstring flexibility and reducing perceived pain. These aligns with the benefits observed with HR-AC techniques (Masood et al., 2020). In contrast, a more recent study comparing static stretching, PNF, and passive control treatments found no significant difference among the three methods. However, PNF demonstrated the highest effectiveness in reducing pain, improving ROM, and enhancing scores on the lower extremity functional scale (Sohail et al., 2022). This indicates a gap in understanding the comparative effectiveness of these stretching techniques and the need for further investigation into which methods are most beneficial for managing DOMS.

Based on the above explanation, this study aims to identify important insights into managing DOMS (pain reduction) through eccentric exercise and PNF, with a focus on flexibility levels. These findings will help establish effective therapeutic exercise options for trainers and physical therapists to enhance recovery outcomes for individuals experiencing DOMS. The research questions formulated in this study are: (1) Is there a difference between eccentric exercise and PNF in improving flexibility levels and reducing muscle soreness in DOMS? (2) Do high flexibility and low flexibility levels differ regarding reducing muscle soreness in DOMS? (3) Is there an interaction between therapeutic exercise methods (eccentric exercise and PNF) and flexibility levels of muscle soreness in DOMS?

Material and Methods

Research Design

This study employed a quasi-experimental design to investigate the relationship between research variables (Montgomery, 2013). The research used two independent variables: eccentric exercise and flexibility training (PNF). The attribute variable used as a control was the level of flexibility, which was classified into high and low groups. On the other hand, the dependent variable in this study was DOMS (pain level).

To examine the relationships between the variables and the interactions among the independent variables, a 2 x 2 factorial design was employed. The analysis explored both the individual effects of each variable and how they interacted with one another. A clearer illustration of the research design is provided in Table 1.

Table 1. The 2x2 Factorial Design

Method (A) Flexibility (B)	Ecc (A1)	PNF (A2)
High flexibility (B1)	A1B1	A2B1
Low Flexibility (B2)	A1B2	A2B2
Total	A1	A2

Note: The group labels are defined as follows: A1B1 refers to the high-flexibility group that received eccentric exercise, A2B1 to the high-flexibility group that received PNF training, A1B2 to the low-flexibility group that received eccentric exercise, and A2B2 to the low-flexibility group that received PNF training. A1 represents the group that received eccentric exercise, while A2 denotes the group that received PNF training, and Ecc stands for eccentric training.

Participants

Participants were recruited using a purposive sampling technique based on specific criteria and their willingness to participate in the full study program. This willingness was evidenced through informed consent, stating their rights as participants in this research, including the right to withdraw at any research phase. They were selected according to predefined inclusion and exclusion criteria. The inclusion criteria for the study were male participants, individuals engaging in infrequent physical activity, particularly involving the lower extremities, those with no history of acute, subacute, or chronic injuries, and participants without current degenerative diseases (e.g., asthma, heart disease, kidney disease). Others who did not match these criteria were excluded. Following recruitment, 60 male sports science students were chosen to participate in the study. The

participants had a mean age of 21.3 ± 8.4 years, a mean body weight of 73.5 ± 2.32 kg, a mean height of 163.3 ± 5.26 cm, and a body mass index (BMI) of 27.56 ± 2.13 .

Procedure

Distribution of treatment groups

The research procedure began with obtaining approval for the research. After that, the training program was designed, and participants were recruited using purposive sampling based on the inclusion criteria. Once selected, flexibility measurements and general demographic assessments (e.g., height, weight, age) were conducted. To identify the highest and lowest flexibility levels within the sample, percentage techniques were employed (Miller, 2008). As a result, 27% ($n = 30$) of participants were classified into the high flexibility group (B1), while another 27% ($n = 30$) were classified into the low flexibility group (B2).

All participants signed consent forms indicating their willingness to participate in the full series of study procedures. Participants were divided into four groups: A1B1, A1B2, A2B1, and A2B2. Ethical approval was granted by the ethics committee at Universitas Negeri Padang. The illustration of the participants' recruitment process is presented in Figure 2.

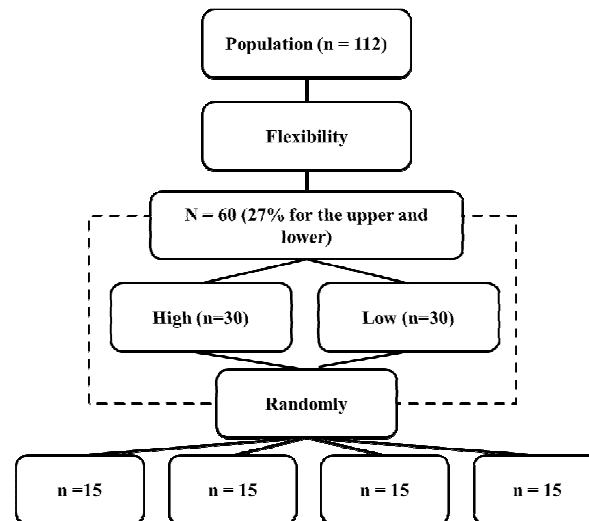


Figure 1. The flow of treatment group assignments in the research

Table 2. The sample size for each treatment group

Flexibility (B)	Training methods (A)				Total (n)
	Ecc (A1)	n	PNF (A2)	n	
High (B1)	A1B1	15	A2B1	15	30
Low (B2)	A1B2	15	A2B2	15	30
Total	A1	30	A2	30	60

PNF stretching and eccentric exercise treatment

The treatment consisted of 5 sets per session, administered 24, 48, and 72 hours after the induction of DOMS over one week. In the PNF stretching group, the quadriceps muscles of participants with DOMS were passively flexed until discomfort was felt, followed by concentric resistance applied below the pain threshold (minimal to moderate) for 7 seconds by the examiner. Participants then took two deep breaths to relax the quadriceps femoris muscles. The hamstring muscles were actively extended until the pain was perceived, with concentric resistance applied similarly below the pain threshold. This process was repeated for 5 sets for each participant in the experimental group, with a 30-second rest period between sets.

The eccentric exercise was administered based on 1 repetition maximum (1-RM), with the same treatment duration as the PNF exercises. The intensity was set to light-submaximal levels, utilizing body weight and external loads, considering 1-RM after the induction of DOMS. Eccentric training is also recognized as an effective therapy for reducing DOMS severity and alleviating associated pain. Focus was placed on engaging supporting muscles while avoiding sore muscles to prevent further stress.

Induction of Delayed-Onset Muscle Soreness (DOMS)

Eccentric Exercise

Participants were instructed to lift a weight corresponding to their maximum capacity for one repetition (1 RM) using their non-dominant arm through the full range of motion in a deadlift movement. The induction of Delayed-Onset Muscle Soreness (DOMS) began by reducing the load to 60% of their 1 RM and performing 13 repetitions, maintaining a descent rate of 10 seconds for each repetition. A rest period of 60 seconds was permitted between sets, and the exercise was terminated when participants could no longer sustain the descent rate for 8 to 10 seconds.

Data Collection Techniques

Data on flexibility were collected using validated and reliable tests (Hoffmann et al., 2019; Vernetta et al., 2020). Muscle soreness in the lower extremities during flexion and extension was measured using a Visual Analog Scale (VAS), consisting of a 100 mm line marked with "no pain" (0 mm) at one end and "extreme pain" (100 mm) at the other. Participants then indicated their pain level along the line under examiner supervision. VAS evaluations were conducted before eccentric training, on the third-day post-exercise, and after treatment for six days.

Data Analysis Techniques

All data collected via the VAS for muscle soreness were tested to meet the assumptions for advanced statistical analysis. Normality was assessed using the Kolmogorov-Smirnov (KS) test, while homogeneity of variances was evaluated using Levene's Test. A two-way ANOVA was then conducted to compare the groups. If significant effects were found, post-hoc Tukey's tests were needed to examine specific group differences. The significance level was set at $\alpha = 0.05$, and all statistical analyses were performed using SPSS version 25.

The statistical hypotheses to be tested in this study can be outlined as follows:

First Hypothesis

- $H_0: \mu A_1 = \mu A_2$
- $H_1: \mu A_1 > \mu A_2$

Second Hypothesis

- $H_0: \mu B_1 = \mu B_2$
- $H_1: \mu B_1 > \mu B_2$

Third Hypothesis

- $H_0: \text{Interaction } (A \times B) = 0$
- $H_1: \text{Interaction } (A \times B) \neq 0$

Note: H_0 represents the null hypothesis, while H_1 refers to the alternative hypothesis. μA_1 denotes the average muscle soreness score for the eccentric training group, and μA_2 represents the average score for the PNF training group. μA_1B_1 corresponds to the high flexibility group using PNF, μA_2B_1 to the high flexibility group using eccentric training, μA_1B_2 to the low flexibility group using PNF, and μA_2B_2 to the low flexibility group using eccentric training. **A** indicates exercise methods, and **B** refers to flexibility levels.

Results

Data description

Before presenting the results of the two-way ANOVA, the following table displays the mean scores for the reduction in pain levels across the various research groups. Table 3 and Figure 3 below provide a clearer presentation of the results.

Table 3. Description of data on the reduction of muscle soreness in sports science students

Exercise	Level of Flexibility	Mean	Standard Deviation	N
Eccentric	• High (A1B1)	6.47	0.990	15
	• Low (A1B2)	6.13	0.915	15
	Total	6.30	0.952	30
PNF	• High (A2B1)	5.07	0.799	15
	• Low (A2B2)	3.13	0.743	15
	Total	4.10	1.242	30
Total	• High (B1)	5.77	1.135	30
	• Low (B2)	4.63	1.732	30
	Total	5.20	1.560	60

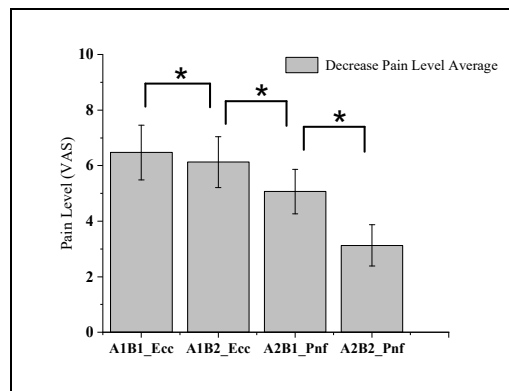


Figure 2. Decrease Pain Level Average

The normality of the data distribution in this study was assessed using the Kolmogorov-Smirnov test. The calculations were performed using SPSS version 25 and showed that the data followed a normal distribution, with a Kolmogorov-Smirnov Z value of 1.283 and $p > 0.05$, confirming normality. In addition, the second prerequisite for conducting a two-way ANOVA, the homogeneity of variance, was evaluated using Levene's test. The obtained F value was 1.212, with $p > 0.05$, indicating homogeneity. Therefore, both prerequisites for the two-way ANOVA were satisfied.

The results of the subsequent analysis are summarized in Table 4 for the two-way analysis of variance (ANOVA).

Table 4. Summary of the two-way ANOVA analysis on muscle soreness reduction in DOMS

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	101.467 ^a	3	33.822	44.954	0.000	
Intercept	1622.400	1	1622.400	2156.354	0.000	
A	72.600	1	72.600	96.494	0.000	
B	19.267	1	19.267	25.608	0.000	
A * B	9.600	1	9.600	12.759	0.001	
Error	42.133	754	0.752			
Total	1766.000	758				
Corrected Total	143.600	757				

^a R Squared = .707 (Adjusted R Squared = 0.691). In this context, **A** represents eccentric training, **A1** indicates high flexibility, **A2** indicates low flexibility, **B** refers to PNF training, **B1** indicates high flexibility in the PNF group, and **B2** indicates low flexibility in the PNF group.

The two-way ANOVA table shows a significant difference in the reduction of muscle soreness associated with delayed-onset muscle soreness (DOMS) between eccentric training and proprioceptive neuromuscular facilitation (PNF). This is evidenced by an F value of 96.494 and a p-value of 0.000, confirming statistical significance ($p < 0.05$). The mean reduction in muscle soreness with eccentric training was 6.30, which was greater than the reduction of 4.10 observed with PNF. These findings suggest that eccentric training is more effective in reducing muscle soreness associated with DOMS. Based on these results, the null hypothesis (H_0) is rejected, and the alternative hypothesis (H_1) is accepted. Therefore, it can be concluded that there is a significant difference between eccentric training and PNF in reducing muscle soreness caused by DOMS.

Furthermore, the data analysis results revealed a significant difference in the reduction of muscle soreness in DOMS between individuals with high flexibility and those with low flexibility. This is evidenced by an F value of 25.608 and a p-value of 0.000, confirming statistical significance ($p < 0.05$). The mean reduction in muscle soreness for individuals with high flexibility was 5.77, which was greater than the reduction observed in those with low flexibility by 4.63. This finding demonstrates that high flexibility is associated with a greater reduction in muscle soreness in DOMS compared to low flexibility. Based on this analysis, the null hypothesis (H_0) is rejected, and the alternative hypothesis (H_1) is accepted. It can be concluded that there is a significant difference in the reduction of muscle soreness in DOMS between individuals with high and low flexibility levels. Those possessing high flexibility exhibit a greater reduction in muscle soreness compared to those with low flexibility. Lastly, the two-way ANOVA results showed a significant interaction between the therapeutic exercise methods (eccentric training and PNF) and flexibility levels concerning reducing muscle soreness in DOMS. This is evidenced by an F value of 12.759 and a p-value of 0.001, confirming statistical significance at $p < 0.05$. This interaction is visually illustrated in Figure 4.

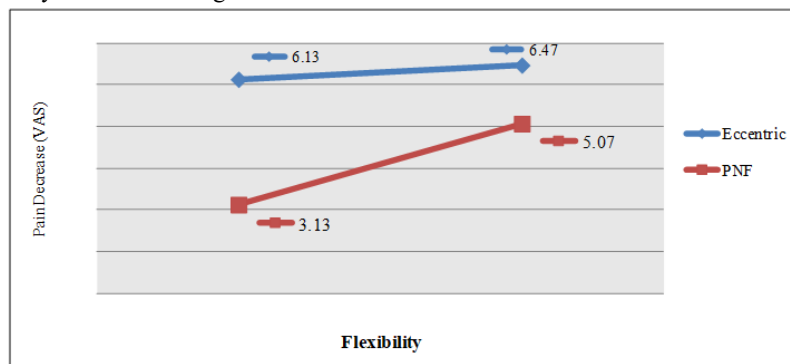


Figure 3. Interaction between therapeutic exercise methods and flexibility levels on the reduction of muscle soreness in DOMS

The analysis results show that the null hypothesis (H_0) is rejected, and the alternative hypothesis (H_1) is accepted. This indicates a significant interaction between therapeutic exercise methods (eccentric training and PNF) and flexibility levels in reducing muscle soreness in DOMS.

Discussion

The overall findings of this study confirm the statistical significance of changes in the investigated variables and the improvements in the experimental group performances, which were influenced by their assigned treatment groups. The data demonstrate that eccentric training was significantly more effective than proprioceptive neuromuscular facilitation (PNF) stretching in reducing pain associated with delayed-onset muscle soreness (DOMS). This is evidenced by an F-value of 96.494 and a p-value of 0.000, confirming that $p < 0.05$. Additionally, the average pain reduction score in the eccentric training group was 6.30, compared to 4.10 in the PNF stretching group. This finding highlights a clear preference for eccentric training in managing DOMS. These results strongly suggest that eccentric training is a more effective therapeutic approach for reducing DOMS-related pain. Previous research supports this conclusion, indicating that active exercise can significantly reduce the severity of DOMS (Ambardini & Kushartanti, 2024).

Given the effectiveness of eccentric training, eccentric training produces a stronger physiological response that alleviates pain by reducing the inflammation caused by micro-injuries in the muscle (Stożer et al., 2020). While eccentric training can induce DOMS, it also enhances muscle hypertrophy and strength (Hody et al., 2019). The pain associated with DOMS is largely due to the recruitment of fewer muscle fibers, muscle elongation stress, micro-tears within the muscle tissue, and pressure on the connective tissues. However, with appropriate eccentric training, recovery from DOMS can be improved. It is important to note that eccentric training, despite causing initial muscle damage, leads to better long-term muscle adaptation (Drury et al., 2019; Fernandez-Gonzalo et al., 2014). When combined with other interventions, such as massage, PNF stretching can also yield beneficial effects, though it is less effective than eccentric training alone (Rudisill et al., 2023).

Regarding flexibility, the results show a significant reduction in pain between individuals with high and low flexibility. The average pain reduction was 5.77 for the high flexibility group, compared to 4.63 for the low flexibility group. This is supported by an F-value of 25.608 and a p-value of 0.000, confirming $p < 0.05$. These findings emphasize the important role of flexibility in the recovery process from DOMS.

While DOMS is a natural part of muscle adaptation after exercise, it can cause discomfort, especially for untrained individuals, which may deter them from continuing physical activity (Ferrara & D'Angelo, 2023; McGrath et al., 2014; Raimi et al., 2020). Implementing recovery strategies that expedite relief from DOMS can encourage untrained individuals to remain engaged in physical exercise.

This study provides essential insights by comparing two recovery techniques—eccentric training and PNF stretching—for DOMS management, thus contributing to the limited research on these methods. However, there are some limitations. The sample size for each group ($n = 15$) suggests future research would benefit from larger sample sizes. Additionally, this study only included male participants, so further investigation can be directed to compare male and female groups to gain a more comprehensive understanding.

Conclusion

This study concludes that eccentric training is more effective in reducing pain than PNF stretching, especially in individuals with high flexibility. The analysis revealed several key findings. First, there was a significant difference in the reduction of DOMS-related pain between eccentric training and PNF stretching, with eccentric training showing a greater reduction in pain.

The statistical results indicated an F-value of 96.494 and a p-value of less than 0.05. Second, a significant difference in pain reduction was observed between individuals with high and low flexibility. Those with high flexibility experienced a greater reduction in muscle soreness, with an average pain reduction of 5.77 compared to 4.63 in those with low flexibility.

The statistical evidence for this was an F-value of 25.608 and $p < 0.05$. Finally, the study found a significant interaction between therapeutic exercise methods and flexibility levels. These results were marked by an interaction F-value of 12.759 and $p < 0.05$. These findings suggest that physical therapists should consider individual flexibility when designing recovery strategies, as this could lead to more effective interventions and better outcomes for patients recovering from DOMS.

Acknowledgments

We would like to extend our deepest gratitude to all those who contributed to the successful completion of this study. We are especially thankful to the participants who volunteered their time and effort to engage in the research procedures, making this study possible. We also wish to acknowledge the ethics committee at Universitas Negeri Padang for granting approval for this study and the administrative staff for their invaluable support in coordinating the research logistics. The Author would like to thank to the Lembaga Penelitian dan Pengabdian Masyarakat (LPPM) Universitas Negeri Padang for funding this work with a contract number: 1478/UN35.15/LT/2024.

Conflicts of interest

There is no conflict of interest to declare.

References

- Afonso, J., Clemente, F. M., Nakamura, F. Y., Morouço, P., Sarmiento, H., Inman, R. A., & Ramirez-Campillo, R. (2021). The Effectiveness of Post-exercise Stretching in Short-Term and Delayed Recovery of Strength, Range of Motion and Delayed Onset Muscle Soreness: A Systematic Review and Meta-Analysis of Randomized Controlled Trials. *Frontiers in Physiology*, 12(May). <https://doi.org/10.3389/fphys.2021.677581>
- Akl, A. R. (2013). The role of biomechanical parameters and muscle activity during eccentric and concentric contractions in vertical jump performance. *Journal of Physical Education and Sport*, 13(3), 430–437. <https://doi.org/10.7752/jpes.2013.03069>
- Alsultan, F., Cescon, C., Heneghan, N. R., Rushton, A., Barbero, M., & Falla, D. (2020). Eccentric exercise and delayed onset muscle soreness reduce the variability of active cervical movements. *Journal of Biomechanics*, 111, 109962. <https://doi.org/10.1016/j.jbiomech.2020.109962>
- Ambardini, R. L., & Kushartanti, B. M. W. (2024). Optimizing recovery: how PNF stretching and ice massage alleviate markers of DOMS? *Retos*, 58(8), 560–567. <https://doi.org/10.47197/retos.v58.107992>
- Baxter, C., Mc Naughton, L. R., Sparks, A., Norton, L., & Bentley, D. (2017). Impact of stretching on the performance and injury risk of long-distance runners. *Research in Sports Medicine*, 25(1), 78–90. <https://doi.org/10.1080/15438627.2016.1258640>
- Benford, J., Hughes, J., Waldron, M., & Theis, N. (2021). Concentric versus eccentric training: Effect on muscle strength, regional morphology, and architecture. *Translational Sports Medicine*, 4(1), 46–55. <https://doi.org/10.1002/tsm2.197>
- Boesen, A. P., Hansen, R., Boesen, M. I., Malliaras, P., & Langberg, H. (2017). Effect of High-Volume Injection, Platelet-Rich Plasma, and Sham Treatment in Chronic Midportion Achilles Tendinopathy: A Randomized Double-Blinded Prospective Study. *American Journal of Sports Medicine*, 45(9), 2034–2043. <https://doi.org/10.1177/0363546517702862>
- Bompa, T., & Buzzichelli, C. (2015). *Periodization training for sports*, 3e. Human kinetics.
- Breda, S. J., Oei, E. H. G., Zwerver, J., Visser, E., Waarsing, E., Krestin, G. P., & de Vos, R.-J. (2020). Effectiveness of progressive tendon-loading exercise therapy in patients with patellar tendinopathy: a randomized clinical trial. *British Journal of Sports Medicine*, bjsports-2020-103403. <https://doi.org/10.1136/bjsports-2020-103403>
- Burgos-Jara, C., Cerda-Kohler, H., Aedo-Muñoz, E., & Miarka, B. (2023). Eccentric Resistance Training: A Methodological Proposal of Eccentric Muscle Exercise Classification Based on Exercise Complexity, Training Objectives, Methods, and Intensity. *Applied Sciences (Switzerland)*, 13(13). <https://doi.org/10.3390/app13137969>
- Cannell, L. J., Taunton, J. E., Clement, D. B., Smith, C., & Khan, K. M. (2001). A randomized clinical trial of the efficacy of drop squats or leg extension/leg curl exercises to treat clinically diagnosed jumper's knee in athletes: Pilot study. *British Journal of Sports Medicine*, 35(1), 60–64. <https://doi.org/10.1136/bjsm.35.1.60>
- Cha, H. G., & Kim, M. K. (2015). Effects of the hold and relax-agonist contraction technique on recovery from delayed onset muscle soreness after exercise in healthy adults. *Journal of Physical Therapy Science*, 27(10), 3275–3277. <https://doi.org/10.1589/jpts.27.3275>
- De Oliveira, F., Paz, G. A., Corrêa Neto, V. G., Alvarenga, R., Marques Neto, S. R., Willardson, J. M., & Miranda, H. (2023). Effects of Different Recovery Modalities on Delayed Onset Muscle Soreness, Recovery Perceptions, and Performance Following a Bout of High-Intensity Functional Training. *International Journal of Environmental Research and Public Health*, 20(4), 1–12. <https://doi.org/10.3390/ijerph20043461>
- De Oliveira Júnior, J. D., DE LIMA PINTO, J. C. B., De Caldas Honorato, R., De Barros, A. C. M., Da Silva Santos, T. R., & Mortatti, A. L. (2018). The acute effect of proprioceptive neuromuscular facilitation in explosive force and jump resistance of basketball players. *Journal of Physical Education and Sport*, 18(2), 632–636. <https://doi.org/10.7752/jpes.2018.02092>
- Drury, B., Ratel, S., Clark, C. C. T., Fernandes, J. F. T., Moran, J., & Behm, D. G. (2019). Eccentric resistance training in youth: Perspectives for long-term athletic development. *Journal of Functional Morphology and Kinesiology*, 4(4), 1–33. <https://doi.org/10.3390/jfmk4040070>
- Eken, Ö., & Bayer, R. (2022). Acute effects of proprioceptive neuromuscular facilitation stretching, massage and combine protocols on flexibility, vertical jump and hand grip strength performance in kickboxers. *Pedagogy of Physical Culture and Sports*, 26(1), 4–12. <https://doi.org/10.15561/26649837.2022.0101>
- Fatouros, I. G., & Jamurtas, A. Z. (2016). Insights into the molecular etiology of exercise-induced inflammation: Opportunities for optimizing performance. *Journal of Inflammation Research*, 9, 175–186. <https://doi.org/10.2147/JIR.S114635>
- Fernandez-Gonzalo, R., Lundberg, T. R., Alvarez-Alvarez, L., & de Paz, J. A. (2014). Muscle damage responses and adaptations to eccentric-overload resistance exercise in men and women. *European Journal of Applied Physiology*, 114(5), 1075–1084. <https://doi.org/10.1007/s00421-014-2836-7>

- Ferrara, L., & D'Angelo, S. (2023). Post-exercise fatigue, lactate, and natural nutritional strategy. *Journal of Physical Education and Sport*, 23(9), 2274–2283. <https://doi.org/10.7752/jpes.2023.09261>
- Gashi, A. I., Kovačič, T., Gashi, F., & Azemi, A. (2023). The effect of proprioceptive neuromuscular facilitation technique on treating cervical radiculopathy. *Journal of Physical Education and Sport*, 23(3), 722–729. <https://doi.org/10.7752/jpes.2023.03089>
- Gokce, E., Akat, F., Dursun, A. D., Gunes, E., Bayram, P., Billur, D., & Koc, E. (2019). Effects of eccentric exercise on different slopes. *Journal of Musculoskeletal Neuronal Interactions*, 19(4), 412–421.
- Gregory, N. S., Whitley, P. E., & Sluka, K. A. (2015). Effect of intramuscular protons, lactate, and atp on muscle hyperalgesia in Rats. *PLoS ONE*, 10(9), 1–13. <https://doi.org/10.1371/journal.pone.0138576>
- Hody, S., Croisier, J. L., Bury, T., Rogister, B., & Leprince, P. (2019). Eccentric muscle contractions: Risks and benefits. *Frontiers in Physiology*, 10(MAY), 1–18. <https://doi.org/10.3389/fphys.2019.00536>
- Hoffmann, M. D., Colley, R. C., Doyon, C. Y., Wong, S. L., Tomkinson, G. R., & Lang, J. J. (2019). Normative-referenced percentile values for physical fitness among Canadians. *Health Reports*, 30(10), 14–22. <https://doi.org/10.25318/82-003-x201901000002-eng>
- Ilham, Agus, A., Tomoliyus, Sugiyanto, F. X., Tirtawirya, D., Lumintuarso, R., Berhimpong, M. W., Alsyifa, R. A., Kurniawan, R., Effendi, R., Ayubi, N., Alben, A. S. C., Perdana, G. S., Rifki, M. S., Ndayisenga, J., Sibomana, A., & Jean-Berchman, B. (2024). Comparative Analysis of Adaptations Progress in VO2max , Leg Power , and Agility among Male and Female Sports Science Students Análisis Comparativo del Progreso de las Adaptaciones en VO2max , Potencia de Piernas y Agilidad entre Estudiantes Masculinos y. *Retos*, 57(7), 245–257.
- Kancherla, A. S. (2023). Delayed Onset Muscle Soreness (DOMS): Management Update. *Annals of Innovation in Medicine*, 1(3). <https://doi.org/10.59652/aim.v1i3.79>
- Keriven, H., Sánchez-Sierra, A., Miñambres-Martín, D., González de la Flor, Á., García-Pérez-de-Sevilla, G., & Domínguez-Balmaseda, D. (2023). Effects of peripheral electromagnetic stimulation after an eccentric exercise-induced delayed-onset muscle soreness protocol in professional soccer players: a randomized controlled trial. *Frontiers in Physiology*, 14(July), 1–9. <https://doi.org/10.3389/fphys.2023.1206293>
- Khodayari, B., & Dehghani, Y. (2012). The Investigation of Mid-term Effect of Different Intensity of PNF Stretching on Improve Hamstring Flexibility. *Procedia - Social and Behavioral Sciences*, 46, 5741–5744. <https://doi.org/10.1016/j.sbspro.2012.06.508>
- Kisner, C., & Colby, L. A. (2007). Therapeutic Exercise: Foundations and Techniques. In M. Biblis, D. J. Thorp, & C. O'brien (Eds.), *Davisplus* (5th ed.). Biblis, Margaret.
- Kommers, M. J., Reis da Silva Duarte, J. D., Rezende Fett, W. C., Da Silva Rocha, L. C., Costa e Cunha Moraes Brandão, C. F., & Fett, C. A. (2024). Comparison of four methods in recovery delayed onset muscle soreness. *Journal of Human Sport and Exercise*, 19(4), 1151–1159. <https://doi.org/10.55860/fpr04413>
- Martínez-Gago, A., García-Mesa, Y., Cuendias, P., Martín-Cruces, J., Abellán, J. F., García-Suárez, O., & Vega, J. A. (2024). Sensory innervation of the human shoulder joints in healthy and in chronic pain shoulder syndromes. *Annals of Anatomy*, 252. <https://doi.org/10.1016/j.aanat.2023.152206>
- Masood, K., Riaz, H., Ghous, M., & Iqbal, M. (2020). Comparison between dynamic oscillatory stretch technique and static stretching in reduced hamstring flexibility in healthy population: A single blind randomized control trial. *Journal of the Pakistan Medical Association*, 70(11), 1908–1912. <https://doi.org/10.5455/JPMA.24472>
- McGrath, R. P., Whitehead, J. R., & Caine, D. J. (2014). The Effects of Proprioceptive Neuromuscular Facilitation Stretching on Post-Exercise Delayed Onset Muscle Soreness in Young Adults. *International Journal of Exercise Science*, 7(1), 14–21. <http://www.ncbi.nlm.nih.gov/pubmed/27182398%0Ahttp://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=PMC4831894>
- Menezes, M. A., Menezes, D. A., Vasconcelos, L. L., & DeSantana, J. M. (2022). Is Electrical Stimulation Effective in Preventing or Treating Delayed-onset Muscle Soreness (DOMS) in Athletes and Untrained Adults? A Systematic Review With Meta-Analysis. *Journal of Pain*, 23(12), 2013–2035. <https://doi.org/10.1016/j.jpain.2022.05.004>
- Miller, P. W. (2008). *Measurement and Teaching* (1st ed.). Patrick W. Miller and Associates.
- Mizumura, K., & Taguchi, T. (2024). Neurochemical mechanism of muscular pain: Insight from the study on delayed onset muscle soreness. *The Journal of Physiological Sciences: JPS*, 74(1), 4. <https://doi.org/10.1186/s12576-023-00896-y>
- Monajati, A., Larumbe-Zabala, E., Goss-Sampson, M., & Naclerio Naclerio, F. (2016). The effectiveness of injury prevention programs to modify risk factors for non-contact anterior cruciate ligament and hamstring injuries in uninjured team sports athletes: A systematic review. *PLoS ONE*, 11(5), 1–15. <https://doi.org/10.1371/journal.pone.0155272>
- Montgomery, D. C. (2013). Design and Analysis of Experiments. In L. Ratts, L. Buonocore, A. Melhorn, C. Ruel, H. Nolan, & M. Eide (Eds.), *Design* (8th ed., Vol. 2). John Wiley & Sons, Inc. http://catalog.uab.cat/record=b1764873~S1*cat

- Muanjai, P., Srijunto, W., Werasirirat, P., Mickevicius, M., & Namsawang, J. (2022). Alterations in leg flexibility, joint stiffness, and muscle architecture following a single bout of stretching and eccentric exercise in female older adults. *Journal of Physical Education and Sport*, 22(11), 2743–2753. <https://doi.org/10.7752/jpes.2022.11348>
- Nahon, R. L., Silva Lopes, J. S., & Monteiro de Magalhães Neto, A. (2021). Physical therapy interventions for the treatment of delayed onset muscle soreness (DOMS): Systematic review and meta-analysis. *Physical Therapy in Sport*, 52, 1–12. <https://doi.org/10.1016/j.ptsp.2021.07.005>
- Papadimitriou, K., Loupos, D., Tsalis, G., & Manou, B. (2017). Effects of proprioceptive neuromuscular facilitation (PNF) on swimmers leg mobility and performance. *Journal of Physical Education and Sport*, 17(2), 663–668. <https://doi.org/10.7752/jpes.2017.02099>
- Paulsen, G., Mikkelsen, U. R., Raastad, T., & Peake, J. M. (2012). Leucocytes, cytokines and satellite cells: What role do they play in muscle damage and regeneration following eccentric exercise? *Exercise Immunology Review*, 18(May 2014), 42–97.
- Peake, J. M., Neubauer, O., Gatta, P. A. D., & Nosaka, K. (2017). Muscle damage and inflammation during recovery from exercise. *Journal of Applied Physiology*, 122(3), 559–570. <https://doi.org/10.1152/jappphysiol.00971.2016>
- Peterson, R. A., König, C., Zimmermann, K., Barry, C. M., Wiklendt, L., & Brookes, S. J. H. (2020). Effects of Lactate on One Class of Group III (CT3) Muscle Afferents. *Frontiers in Cellular Neuroscience*, 14(August), 1–16. <https://doi.org/10.3389/fncel.2020.00215>
- Proske, U., & Morgan, D. L. (2001). Muscle damage from eccentric exercise: mechanism, mechanical signs, adaptation and clinical applications. *Journal of Physiology*, 2(537), 333–345.
- Raimi, F., Jawis, M., Hashim, H., & Zainuddin, Z. (2020). Single one-off dose of Nigella Sativa does not attenuate indirect markers of exercise-induced muscle damage as a model of inflammation. *Journal of Physical Education and Sport*, 20(3), 1444–1454. <https://doi.org/10.7752/jpes.2020.03199>
- Rizqi, F., & Ambardini, R. (2019). *The Effectiveness of Combination PNF Stretching and Cryotherapy in The Prevention DOMS at the Lower Extremity*. 330(Iceri 2018), 430–433. <https://doi.org/10.2991/iceri-18.2019.90>
- Rudisill, S. S., Varady, N. H., Kucharik, M. P., Eberlin, C. T., & Martin, S. D. (2023). Evidence-Based Hamstring Injury Prevention and Risk Factor Management: A Systematic Review and Meta-analysis of Randomized Controlled Trials. *The American Journal of Sports Medicine*, 51(7), 1927–1942. <https://doi.org/10.1177/03635465221083998>
- Sabouri, M., Taghibeikzadehbahr, P., Shabkhiz, F., Izanloo, Z., & Shaghaghi, F. A. (2022). Effect of eccentric and concentric contraction mode on myogenic regulatory factors expression in human vastus lateralis muscle. *Journal of Muscle Research and Cell Motility*, 43(1), 9–20. <https://doi.org/10.1007/s10974-021-09613-x>
- Sohail, M. A. A., Tahir, R., Maqbool, A., Hanif, S., & Saeed, O. (2022). Comparing the effectiveness of static stretching and proprioceptive neuromuscular facilitation stretching in treating delayed onset muscle soreness in calf muscles of runners. *Anaesthesia, Pain and Intensive Care*, 26(1), 31–38. <https://doi.org/10.35975/apic.v26i1.1763>
- Sohail, M. U., Yassine, H. M., Sohail, A., & Al Thani, A. A. (2019). Impact of Physical Exercise on Gut Microbiome, Inflammation, and the Pathobiology of Metabolic Disorders. *The Review of Diabetic Studies : RDS*, 15, 35–48. <https://doi.org/10.1900/RDS.2019.15.35>
- Stožer, A., Vodopivec, P., & Bombek, L. K. (2020). Pathophysiology of exercise-induced muscle damage and its structural, functional, metabolic, and clinical consequences. *Physiological Research*, 69(4), 565–598. <https://doi.org/10.33549/physiolres.934371>
- Tenberg, S., Nosaka, K., & Wilke, J. (2022). The Relationship Between Acute Exercise-Induced Changes in Extramuscular Connective Tissue Thickness and Delayed Onset Muscle Soreness in Healthy Participants: A Randomized Controlled Crossover Trial. *Sports Medicine - Open*, 8(1). <https://doi.org/10.1186/s40798-022-00446-7>
- Tomalka, A. (2023). Eccentric muscle contractions: from single muscle fibre to whole muscle mechanics. *Pflugers Archiv European Journal of Physiology*, 475(4), 421–435. <https://doi.org/10.1007/s00424-023-02794-z>
- Vancini, R. L., Pesquero, J. B., Fachina, R. J., Andrade, M. D. S., Borin, J. P., Montagner, P. C., & de Lira, C. A. B. (2014). Genetic aspects of athletic performance: the African runners phenomenon. *Open Access Journal of Sports Medicine*, 5, 123–127. <https://doi.org/10.2147/OAJSM.S61361>
- Vernetta, M., Peláez-Barrios, E. M., & López-Bedoya, J. (2020). Systematic review of flexibility tests in gymnastics. *Journal of Human Sport and Exercise*, 17(1), 1–16. <https://doi.org/10.14198/JHSE.2022.171.07>
- Wackerhage, H. (2003). Recovering from eccentric exercise: Get weak to become strong. *Journal of Physiology*, 553(3), 681. <https://doi.org/10.1113/jphysiol.2003.055798>
- Warneke, K., Rabitsch, T., Dobert, P., & Wilke, J. (2024). The effects of static and dynamic stretching on deep

- fascia stiffness: a randomized, controlled cross-over study. *European Journal of Applied Physiology*, 124(9), 2809–2818. <https://doi.org/10.1007/s00421-024-05495-2>
- Wilke, J., & Behringer, M. (2021). Is “delayed onset muscle soreness” a false friend? The potential implication of the fascial connective tissue in post-exercise discomfort. *International Journal of Molecular Sciences*, 22(17). <https://doi.org/10.3390/ijms22179482>
- Živanović, V. (2022). The effects of different conditioning contraction protocols of post-activation performance enhancement on variables of eccentric phases and concentric phase of vertical jumps. *Journal of Physical Education and Sport*, 22(7), 1694–1707. <https://doi.org/10.7752/jpes.2022.07213>
- Zulaini, Harahap, N. S., Siregar, N. S., & Zulfahri. (2021). Effect Stretching and Recovery on Delayed Onset Muscle Soreness (DOMS) after Exercise. *Journal of Physics: Conference Series*, March 2023. <https://doi.org/10.1088/1742-6596/1811/1/012113>