Journal of Physical Education and Sport ® (JPES), Vol. 24 (issue 4), Art 106, pp. 934 - 941, April 2024
online ISSN: 2247 - 806X; p-ISSN: 2247 – 8051; ISSN - L = 2247 - 8051 © JPES

Original Article

Evidence-based discriminant analysis: A new approach to assessing athletes' latent myofascial trigger point profile

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Published online: April 30, 2024
(Accepted for publication April 15, 2024
DOI:10.7752/jpes.2024.04106

Abstract
Introduction: Latent trigger points (TrPs) are a type of musculoskeletal disorder. That can detrimentally affect athletic performance. **Purpose:** This study to classify athletes into latent-trigger point (L-TrPs) and non-trigger point (non-TrPs) group base on pain pressure threshold (PPT), force production and range of motion (ROM). **Materials and methods:** Total 45 L-TrPs and 45 non-TrPs athletes were selected. The diagnostic criteria proposed by Simons were employed to identify L-TrPs. Pressure algometry was used for PPT, HUMAC NORM ISOKINETIC machine for force production and Kinovea software for ROM analysis. Independent t test and discriminant analysis were conducted. Standardized discriminant coefficient, canonical correlation and Wilks' Lambda was calculated and p-value was judges at 5% level of significance. **Results:** Standardized discriminant coefficient showing that Average PPT hold first position followed by Average Extension ROM followed by Average Flexion ROM while Average force production stands on last position for discriminating ability to classification of the L-TrPs and non-TrPs among the athletes. It also observed that by using PPT, force production, and ROM, the model accurately classifies athletes with both L-TrPs and non- TrPs, with an accuracy ranging from 85% to 93%. This highlights the potential significance of these factors in distinguishing between athletes with and without TrPs. **Conclusion**: From this statistical analysis it concluded that PPT is the most significant contributor to classify the latent and non-TrPs groups. Therefore, regular pain assessment is required to maintain the performance of an individual. Whereas force production and ROM should not be ignored as the model 85%-95% accurately classifies these groups.

Keywords: Force production, Myofascial pain syndrome, Myofascial trigger point, Pain Pressure Threshold, Range of Motion, Athletes

Introduction

Myofascial trigger points (MTrPs), commonly known as trigger points (TrPs), are hyperirritable sites located within tight bands of skeletal muscle fibers (Bethers et al., 2021; Das et al., 2023a). These tender nodules, measuring between 3 and 6 millimeters in diameter (Das, 2022), have garnered significant attention in the realm of musculoskeletal pain research. The presence of TrPs has been associated with myofascial pain, a condition that contributes to a substantial proportion of pain experiences in both males and females (Xia et al., 2017). The TrPs are classified into active (A-TrPs) and latent (L-TrPs). A-TrPs are characterized by their ability to produce continuous pain, whereas L-TrPs do not cause pain unless pressure is applied (Jiménez-Sánchez et al., 2021). The prevalence of TrPs suggests that it is a prominent contributor to pain resulting from various musculoskeletal injuries (Haser et al., 2017; Lee et al., 2020). Understanding TrPs becomes crucial, especially in the field of sports and exercise where athletes often face rigorous physical demands and potential injuries. Moreover, the association between TrPs and sports-related injuries raises concerns about athletes' well-being and performance. Research has highlighted that myofascial pain affects approximately 85% to 93% of people (Koh et al., 2023), and researchers reported that 30–85% of musculoskeletal pain is due to MTrPs (Zhou et al., 2023). Sports-related injuries emphasizing the need to recognize TrPs as a potential cause of musculoskeletal pain in athletes, evidence suggests that 30% of musculoskeletal pain is related to MTrPs (Kamali et al., 2019; Wheeler, 2004). MTrPs are formed by many things, such as training that lasts a long time or isn't consistent, low-load repetitive muscle activity, long-term and short-term mechanical and electrical damage, persistent stress, and prolonged ischemia (Ge & Arendt-Nielsen, 2011). These factors can damage myofibrils and promote the development of L-TrPs, potentially affecting athletes' performance and overall health (Das et al., 2023). The

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impact of MTrPs extends beyond physical discomfort. Athletes suffering from TrPs may reduce muscle flexibility and strength (Das et al., 2023), leading to compromised physical performance (Fousekis & Kounavi, 2016; Haser et al., 2017). Moreover, positive correlations with psychological factors show that TrPs can influence athletes' psychological well-being (San-Antolen et al., 2020; San-Antolen-Gil et al., 2022). Researchers conducted studies on MTrPs and their treatment procedures, with the majority focusing solely on the symptoms of A-TrPs. Researchers reported using manual palpation during a physical examination to assess signs and symptoms associated with MTrPs (Baeumler et al., 2023). Practitioners frequently accept the presence of a local twitch response upon stimulation of A-TrPs as a diagnostic sign (Mazza et al., 2021). Most studies report that symptoms of A-TrPs include low muscular strength, low flexibility, local twitch response, and pain (Haser et al., 2017; Lucena-Anton et al., 2022). Very few studies are available on L-TrPs; therefore, it's become important to conduct more studies in this area.

This research article provides a comprehensive review of existing literature on the prevalence, classification, and impact of L-TrPs on athletes. By exploring the latest research findings, we aim to contribute to a deeper understanding of L-TrPs and their implications for athletes' well-being and performance. From a sportspersons and coach's viewpoint, it's important to know the symptoms of L-TrPs. This allows them to prevent the occurrence of A-TrPs and maintain their performance at the highest level. Therefore, the present study aimed to determine the relative importance of various variables in differentiating L-TrPs from non-TrPs athletes. We also conducted the study to predict the most effective classifier variable and formulate a classification equation that distinguishes L-TrPs from non-TrPs athletes.

Material and methods:

Participants: In this study sample size was determined by G-power software (Version 3.1.9.7), following criterion was consider for sample size determination: A 1-tailed hypothesis with 0.55 (medium effect size), an error probability (1-β) of 0.80 and an α error probability of 0.05 provided, an estimated sample size given 84, therefore, a cohort of 90 elite athletes at the national level was randomly sampled from Madhya Pradesh, India. The research was conducted at the Exercise Physiology laboratory of Lakshmibai National Institute of Physical Education in Gwalior, India. To identify L-TrPs, we employed the diagnostic criteria proposed by Simons et al. These criteria include: (1) the presence of a taut band of muscle; (2) tenderness and heightened sensitivity at a specific spot; and (3) the elicitation of referred pain when applying pressure to the TrP (Zuil-Escobar et al., 2015). Two conditions served as the foundation for the L-TrPs group's admission criterion. First, presences of L-TrPs in the hamstring and quadriceps muscle groups. Second, the participants had to be male athletes who competed in sports that required significant jumping, running, twisting, turning, acceleration, and deceleration. On the other hand, the lack of a perceptible tight band in the muscles was the inclusion criterion for the non-TrPs group. The exclusion criteria employed in this study were comprehensive and aimed at ensuring the validity of the results. Firstly, individuals were excluded if they were presently dealing with any injury or illness, including systemic muscular or neural diseases, as well as any lower limb or lower back injury within the previous three months. Secondly, the study excluded subjects who had recently been diagnosed with or received treatment for fibromyalgia, experienced vascular or neural conditions, or received treatment for MTrPs. Subjects who met the predefined inclusion criteria were provided with a thorough explanation of the study, and their participation was voluntary. the first group, comprising 45 subjects diagnosed as positive for L-TrPs, was selected using purposive sampling. The second group, consisting of subjects without TrPs, also comprised 45 individuals to ensure a balanced sample size for better statistical analysis. The testing process was supervised by a qualified physiotherapist. The Central Ethics Committee of the institution has approved (approval number: 392/1346/27) the study protocol on 23th February, 2023 and all procedures were performed after obtaining written informed consent.

Pain Pressure Threshold Measurement: In the present study used the FPX 25 Wagner (FPX 25 Wagner Instruments, Greenwich, CT, USA) Instruments pressure algometer to measure PPT (H. Battecha et al., 2021; Das et al., 2022). Pressure algometers are reliable for evaluating pain thresholds and MTrPs (Das & Jhajharia, 2022). Subjects' lower limb (Hamstring and quadriceps muscle group) PPT tested three times with a constant pressure, and the average value was recorded.

Force Production Measurement: The force production was measured by HUMAC NORM ISOKINETIC machine (Computer Sports Medicine, Inc. Stoughton, MA, USA). This test was performed according to the relevant research papers (Tasmektepligil, 2016; Das et al., 2023b;) user manuals guideline. Participants completed a warm-up of the lower limb muscles involved in the testing before the main assessment. Peak isokinetic concentric knee extension and flexion torque of both legs were evaluated at an angular velocity of 180°/s velocity. The knee extension and flexion contractions were performed through a range of 0–90° (full extension is defined as 0 degree). Participants were instructed to flex and extend their leg with maximum force, and scores were recorded by the computer and displayed on the machine's monitor.

Range of Motion Measurement: Kinovea® version 0.9.5 software was used by the researchers to measure the ROM. The software was found to be a valid and reliable tool for measuring accurately at distances up to 5 meters from the object. It is available for free download at (https://www.kinovea.org/) (Puig-Diví et al., 2019; Fernández-González et al., 2020). Participants' knee joint movements were recorded using a GoPro 9 action camera from sagittal and frontal axes. Reflective markers were placed on specific anatomical points for assessing lateral view angular displacement (E Silva et al., 2018; Fernández-González et al., 2020). The camera, mounted on a tripod 80 cm high and 1.5 m from the participants, was kept at a fixed distance using floor tape. Each participant performed knee flexion and extension while lying prone on a table. Videos were analyzed using Kinovea software, and angles at the greater trochanter, external femoral condyle, and lateral malleolus were measured to describe the knee joint movements.

*Statical Analysis:*Data were coded and entered in Microsoft excel software. Statistical analyses were done using Statistical Package for the Social Sciences (SPSS-26) software. Mean and standard deviation was used to describe various average of the variables. The significance of the difference in Mean of PPT, force production and ROM in L-TrPs and non-TrPs were compared using the independent t-test. Differences were considered statistically significant at $p<0.05$. Discriminant analysis was performed to classify L-MTrPs with non-MTrPs. Standardized discriminant coefficient, canonical correlation and Wilks' Lambda was calculated. Step wise discriminate analysis method was adopted to predict most effective classifier MTrPs. This method ensured that only important variables were selected while redundant variables i.e., those contributing very less in the presence of other variables were discarded from the model with low error rate. The procedure adopted was backward step wise elimination which discarded the variables with smallest F and largest Wilk's lambda step by step. These eliminated variables were used in the model as they are most important and worthy of inclusion into discriminate function. Equation for Discriminant Function of L-TrPs (F1) and non-TrPs were developed using the30 -30 sample and classification accuracy validation was assessed on 15-15 samples. Predictive Classification ability for L-TrPs and non-TrPs were shown using the graphical representation.

Results

In the present study 45 athletes having L-TrPs and 45 athletes without TrPs were observed. The average age of the L-TrPs athletes was 20.47 ± 2.11 years while among the non-TrPs athletes average age was 20.54 ± 2.15 years.

Table 1. Mean comparison of determinants in two groups:

Variables	L-TrPs (n=45)	Non-TrPs (n=45)	t-value	p-value
	Mean ± sd	Mean ± sd		
Average force production	158.80±14.10	169.36±16.84	-3.224	0.002
Average PPT	21.01±1.85	24.97±1.29	-11.72	0.000
Average Flexion ROM	137.26±0.97	137.68±1.39	-1.66	0.099
Average Extension ROM	2.03±0.80	1.99±0.73	0.23	0.817

PPT- Pain Pressure Threshold, ROM- Range of Motion

The mean age was found to be statistically same in both the groups ($p>0.05$). The average force production was observed in L-TrPs and non-TrPs groups were 158.80 ± 14.10 N/m^2 and 169.36 ± 16.84 N/m^2 respectively. Average PPT recorded for L-TrPs and non-TrPs groups were 21.01 ± 1.85 $lbs./cm^2$ and 24.97 ± 1.29 $lbs./cm^2$ respectively. Average Flexion ROM for L-TrPs and non-TrPs groups were 137.26 ± 0.97 degree and 137.68 ± 1.39 degree respectively. Average Extension ROM for L-TrPs and non-TrPs groups were 2.03 ± 0.80 degree and 1.99 ± 0.73 degree. There were statistically significant differences in recorded in Average force production and Average PPT for L-TrPs and non-TrPs groups (Table1).

Table 2. Standardized Canonical Discriminant Function Coefficients for determinants:

Variables	Function	Rank of Importance
Average force production	0.337	4
Average PPT	0.931	1
Average Flexion ROM	0.396	3
Average Extension ROM	0.441	2

PPT- Pain Pressure Threshold, ROM- Range of Motion

Standardized discriminant coefficient showing that Average PPT hold first position followed by Average Extension ROM followed by Average Flexion ROM while Average force production stands on last position for discriminating ability to classification of the L-TrPs and non-TrPs among the athletes (Table 2).

Table 3(A). Step-wise discriminate analysis method to predict most effective classifier variables:

Variables Not in the Analysis					
Step		Tolerance	Min. Tolerance	F to Enter	Wilks' Lambda
0	Average force production	1.000	1.000	11.376	.836
	Average PPT	1.000	1.000	75.954	.433
	Average Flexion ROM	1.000	1.000	1.802	.970
	Average Extension ROM	1.000	1.000	.130	.998
1	Average force production	.999	.999	3.948	.405
	Average Flexion ROM	.998	.998	.355	.430
	Average Extension ROM	.961	.961	1.898	.419
2	Average Flexion ROM	.981	.981	.684	.400
	Average Extension ROM	.959	.959	1.511	.394

PPT- Pain Pressure Threshold, ROM- Range of Motion

Table 3(B). Ability of Predicted classifiers through Wilks' Lambda:

Wilks' Lambda									
Step	Number of Variables	Lambda	df1	df2	df3	Exact F			
						Statistic	df1	df2	Sig.
1	1	.433	1	1	58	75.954	1	58.00	.00
2	2	.405	2	1	58	41.881	2	57.00	.00

Backward Step wise discriminate analysis method was adopted to predict most effective classifier for L-TrPs in athletes. In step 1; Average PPT was selected (wilks lamda = 0.433; F to enter =75.954). In step 2; Average force production was selected (wilks lamda = 0.405; F to enter = 41.881). So, in final discriminant model only two variables i.e., Average Flexion ROM and Average Extension ROM were used but 40.5 % of the total variance in the discriminant scores was not explained by this two -variable model (Table 3 A & Table 3 B).

Table 4. Summary table of Canonical Discriminant Functions

Eigenvalues					Wilks' Lambda				
Function	Eigenvalue	% Of Variance	Cumulative %	Canonical Correlation	Test of Function(s)	Wilks' Lambda	Chi-square	df	P value
1	1.470a	100.0	100.0	0.771	1	.405	51.52	2	.00

a. First 1 canonical discriminant functions were used in the analysis

The canonical correlation was 0.771 showing the good association between the discriminant scores and the trigger points groups. In present study significant Wilks' Lambda for two variable model is 0.405 showing that 40.5 % of the total variance in the discriminant scores not explained by differences among the groups by the two-variable model (Table 4).

Table 5. Fisher's linear discriminant Classification Function Coefficients finally included for classification:

Variables	**Group**	
	Non-TrPs	**L-TrPs**
Average Force Production	0.677	0.626
Average Pressure Pain Threshold	8.884	7.545
(Constant)	-169.076	-129.703
Equation for Discriminant Function of Non-TrPs (F1)	0.677* Average Force Production+8.884* Average Pressure Pain Threshold -169.076	
Equation for Discriminant Function of L-TrPs (F2)	0.626* Average Force Production+7.545* Average Pressure Pain Threshold -129.703	

If F1 > F2; Allot subject as Non-TrPs; If F2> F1; Allot subject as L-TrPs

Table 5 showing the equation of discriminant model for the classification of L-TrPs with the non-TrPs which were formed using the Fisher's discriminant score and constant.

Table 6. Percentage of correct classifications in the Developmental and Cross-validated samples

Actual Group Membership	Predicted Group Membership			
	L-TrPs	**Non-TrPs**	**Total**	**Overall classification**
Developmental Sample: Classification Count				
L-TrPs	24	6	30	85%
Non-TrPs	3	27	30	
Developmental Sample: Classification Percentage				
L-TrPs	80	20	100	
Non-TrPs	10	90	100	
Cross-Validation Sample: Classification Count				
L-TrPs	15	0	15	93.33%
Non-TrPs	2	13	15	
Cross-Validation Sample: Classification Percentage				
L-TrPs	100	00	100	
Non-TrPs	13.3	86.7	100	

Table 6 showing the Developmental Sample model which used 30-30 athletes' data to frame the equations for the classification was able to classify correctly 85 % of L-TrPs with the non-TrPs. While this model when used on fresh data on 15-15 athletes as validating the model classification ability it was found that this model is able to classify 93.33% cases correctly. Which is confirming the accuracy of the model to classify the L-TrPs with the non-TrPs for the athletes.

Figure 1 showing model classification power in separation of L-TrPs with the non-TrPs.

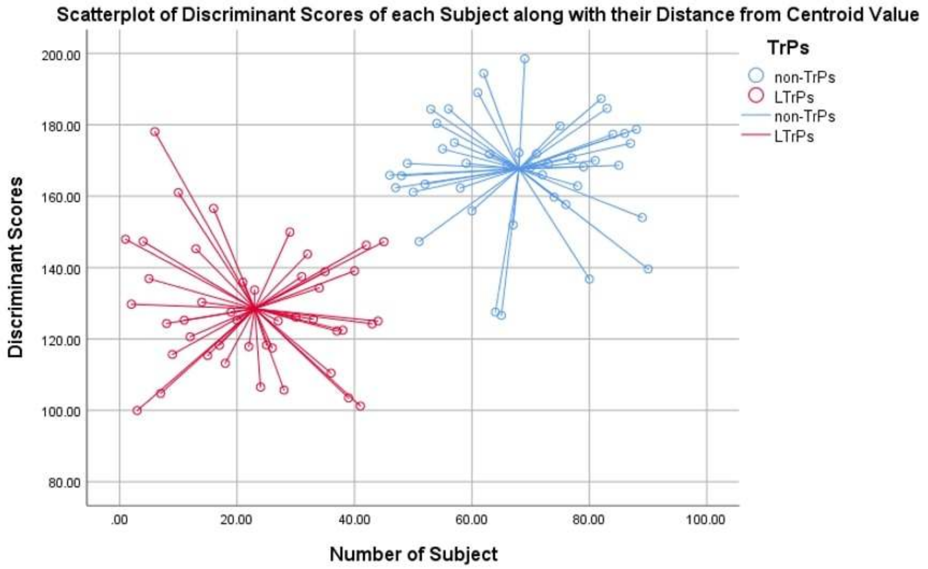

Figure-1 demonstrated this discriminant model accurately classify the both the groups. Blue colour indicate non-TrPs group and red colour indicate L-TrPs.

Discussion

Various authors reported that L-TrPs decreased pain tolerance in that particular area (Cygańska et al., 2022; Das et al., 2023b). Previous research has explained why the PPT is lower when there are trigger points. For example, Simons et al.'s "Understanding Effective Treatments of Myofascial Trigger Points" looked into how trigger points cause pain. The authors hypothesized that trigger points are hyperirritable locations within taut muscle fibre bands. The presence of contraction knots and local biochemical alterations distinguish these spots. Compression or stretching of TrPs can elicit referred pain in distant locations (Simons, 2002). As a result, the presence of TrPs reduced muscle PPT. Some factors mentioned in research articles include local inflammatory processes, peripheral sensitization, and the release of nociceptive substances. These factors contribute to peripheral nerve sensitization and pain transmission (Jin et al., 2020). The available research article suggests that the release of nociceptive chemicals greatly aids in the development and persistence of pain in MTrPs. Which are generated in reaction to tissue injury or inflammation, many sensitize nerve fibres may cause pain perception. There is a buildup of biochemical compounds inside MTrPs, which are localized regions of stiffness and discomfort in the muscles. The standardized discriminant coefficients reveal the ranking of discriminative abilities for classifying the L-TrPs and non-TrPs among athletes, as shown in Table 2. The average PPT has the highest discriminative power, followed by the average extension range of motion and the average flexibility range of motion. On the other hand, Average Force Production demonstrates the lowest discriminative ability in this classification. Therefore, low PPT can be a significant contributor to L-TrPs. For an athlete, it's become necessary to assess the pain threshold level on a regular basis. Previous studies reported that force production (Albin et al., 2020; Sánchez-Infante et al., 2021) and ROM (Charles et al., 2019; Walsh et al., 2019; Öztürk et al., 2022) have a positive correlation with L-TrPs. In this present study, Table 6 shows that this model 85% accurately measures the L-TrPs and non-TrPs groups, which means these three variables are important symptoms for L-MTrPs. As a result, an athlete should not only regularly assess his pain threshold, but also force production and ROM. Existing literature strongly supports the idea that greater muscular strength and joint ROM significantly impact an athlete's performance. Numerous studies have shown that increasing muscular strength and ROM can enhance overall sports skills, including jumping, sprinting, and agility (Pereira et al., 2021).

Athletes with stronger muscles tend to excel in specific sports tasks. Furthermore, increased muscular strength not only leads to better performance but also helps prevent injuries by facilitating potentiation earlier and to a greater extent (Suchomel et al., 2016). TrPs exhaust the muscles easily, making them more sensitive to the activation of additional trigger sites (Pérez-Bellmunt et al., 2021). On the other hand, muscle injuries are more likely to occur when individuals have both low ROM and specific risk factors. Reduced ROM can limit the flexibility and mobility of muscles and joints, making them less adaptable to sudden movements or changes in direction. This limited flexibility may lead to an increased risk of muscle strains, tears, or other types of injuries during physical activities. Moreover, when an individual's ROM is restricted, their muscles may not be able to move through their full range, putting excessive strain on certain muscle fibers or structures during movement. This can result in overloading particular areas of the muscle and potentially leading to injury (Knapik et al., 2019).

Conclusion

In the current study, we found PPT, force production, and ROM are the key components to accurately classify athletes with both L-TrPs and non-TrPs, with an accuracy rate ranging from 85% to 93%. This highlights the potential significance of these factors in distinguishing between athletes with and without TrPs. Due to the high accuracy of classification, it is essential for athletes, coaches, movement experts, and physiotherapists to incorporate routine assessments of PPT, force production, and ROM into their evaluation protocols. These assessments can provide valuable insights into an athlete's musculoskeletal health, potential imbalances, and injury risk, thereby allowing for early intervention and targeted training approaches. Furthermore, sports scientists and physiotherapists should continue to conduct further research in this area, exploring these aspects in more detail that can help identify specific mechanisms and potential causative factors, leading to the development of more effective prevention and treatment strategies. By combining scientific research with practical assessments, sports scientists and physiotherapists can contribute to the advancement of sports performance and injury management. This collaborative effort can ultimately enhance athletes' overall well-being, optimize their training regimens, and minimize the risk of musculoskeletal issues, thus promoting long-term athletic success and health.

Conflicts of interest –

The authors have no conflicts of interest to declare.

Acknowledgments:

The researcher would like to express thanks to the committed athletes who participated in this study. We also acknowledge the invaluable support extended by our institute's research facility during the data collection phase.

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