

Anthropometric and electromyographic characteristics of the free throw shooting gesture in university basketball players

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Abstract:

The free throw in basketball is a shot at the basket awarded after a foul, it depends solely on who makes the shot. Analyzing muscle contractions during a free throw allows the design of sports training programs with an injury prevention component. Objectives: were to determine the anthropometric and electromyographic characteristics in the free throw throwing gesture along with possible associations between the study variables and explore profiles of the athletes using unsupervised machine learning algorithms. Method: 48 university basketball athletes from Manizales-Caldas were included (24 men and 24 women, age = 20,979±4,128 years). The surface electromyographic signal of several muscles involved in the technical gesture was recorded. After measuring the muscular electrical activity in an isometric and dynamic manner, the muscle contraction was estimated through the maximum voluntary contraction, the average of the signal and the maximum values obtained during the throwing gesture were estimated, and the with the endorsement of the institutional bioethics committee through minutes of April 27, 2022. Results: Regarding the maximum voluntary contraction, it was found that the muscles with the greatest contraction in the gesture are the middle deltoid, longissimus dorsi, triceps and flexor radialis longus. . Additionally, a higher fatigue index in dynamic tests than in isometric tests. Regarding the Cluster analysis, three profiles clearly differentiated by anthropometric variables were identified. Conclusions: Most of the participants are overweight, Cluster 3 was characterized by being made up only of men, having anthropometric characteristics superior to the other clusters specifically in height, length and body perimeters such as grip strength, greater isometric fatigue in the muscles dorsal and triceps for taller athletes), compared to the other profiles. On the contrary, greater dynamic fatigue was observed in the dorsal and trapezius muscles in the athletes of profile 2. Regarding the MCV, greater neuromuscular activation was evident in the athletes of profile 1 (athletes of shorter height and record in the anthropometric variables evaluated) Likewise, a higher fatigue index was established in the dynamic tests than in the isometric tests. These results make it possible to make decisions about the free throw gesture and include recommendations in training programs, thus improving the performance of athletes and preventing upper extremity injuries.

Keywords: Body Mass Index, Muscle Fatigue, Exercise, Athletes

Introduction

In basketball, various types of shots, including the free throw – a shooting gesture with consistent characteristics and a clear and reproducible pattern – allow for accurate biomechanical study. A free throw is a shot awarded after a foul. The number of free throws granted depends on the exact action during the shot on which the foul occurred; similarly, according to the National Basketball Association (NBA), every fifth foul committed by a team during the same period, whether technical or personal, results in two free throws for the opposing team (Phatak et al., 2020). The free throw is taken from the line of the same name, located 4.6 meters from the backboard and 5.8 meters from the baseline. Each successful free throw scores one point. This technical gesture is as essential as other shots made from different points on the court, as it can make a difference in the outcomes of a game. Therefore, studying its biomechanical variables has interested various researchers (Button et al., 2003; Huston & Grau, 2003).

Several studies (Echevarría et al., 2011; Díaz-Aroca & Arias-Estero, 2020; Grenha et al., 2021) have employed an observational methodology and provided feedback to athletes, aiming to monitor them through recording instruments that detail the step-by-step execution of the correct free throw technique. However, this methodology is not specialized and does not allow for evaluating variables such as strength, response time, fatigue, and muscle coactivation.

Currently, advanced technology is being used in sports practice to monitor and control abilities and biomechanical variables important for the performance and execution of sports gestures, although there are very few studies in this regard and this is becoming even more generalized at the regional level. Electromyography (EMG), a system that allows the detection and analysis of the electrical signal related to muscle contraction; contributes to understanding neuromuscular patterns and consequences of muscle dysfunctions. (Guzmán & Méndez, 2018). According to the interest of each study, it is possible to carry out different types of analysis thanks to the signal that is displayed as the frequency of muscle contraction, it can be observed from the MVC or maximum voluntary contraction, to muscle fatigue. The MVC helps determine the level of contraction and muscle strength expressed in percentage, thanks to a maximum isometric activity test, and together with the basal contraction test (at rest), they are the reference signals for other tests that involve work. active, isotonic, among others (Román-Liu & Bartuzi, 2018).

Muscle fatigue understood as the loss of a muscle's ability to produce force, is generally the result of prolonged and/or repetitive work, which can generate injuries over the long term. EMG has many advantages for analyzing muscle fatigue in real-time with minimal risks (Phinyomark et al., 2012). It plays a vital role in sports. Many investigations include electromyographic analysis in their study variables; for example, in 2008, the muscular activity in elbow extension was studied according to sports practice, comparing volleyball vs karate athletes, during ballistic movements (Moreno et al., 2008). An electromyographic study was conducted in water polo, where upper limb muscles were selected during different throws. Throwing speed was concluded to be improved by emphasizing strength, endurance, and flexibility training of the pectoralis major and anterior deltoid. Additionally, the study highlighted the stabilizing role of the biceps and triceps brachii muscles in these throws (Yaghoubi et al., 2014).

According to Cerqueira et al. (2013), surface electromyographic activity for biceps brachii is reproducible in protocols involving both isometric (such as maximal strength testing) and dynamic contractions (in this case, during a free throw), which expands the use of surface EMG, making using it in muscle fatigue and even neuromuscular disorders possible. In the case of basketball, although the application of EMG is still relatively scarce, there are studies like that of Lv and Dong (2021), in which surface electromyography was used to analyze muscle discharge time, the rate of contribution, and the integral value of EMG during rotational movements. The goal was to explore the mechanism for preventing various types of injuries. Among the results, a high incidence of knee joint injuries was found, including patellar dislocation, meniscus injury, and cruciate ligament injury, with no difference between genders.

Analyzing the muscle contractions of a high-performance player during a free throw allows for the design and execution of preventive programs to avoid injury mechanisms and improve athletic performance. Therefore, the objective of this study was to determine the anthropometric and electromyographic characteristics in the gesture of the free throw, along with possible associations between the study variables, and to explore profiles of athletes using unsupervised machine learning algorithms in collegiate basketball players.

Materials and Methods

Participants

The study included 48 basketball athletes affiliated with sports clubs from four universities in Manizales-Caldas. The participants comprised 24 men and 24 women, aged between 17 and 45 years (Mean = 20.98 ± 4.13 years).

Procedure

The BTS FreeEmg 1000 8-channel device recorded the surface electromyography signal. This device is a wireless surface electromyograph complying with IEEE 802.15.4 standards. It features a 16-bit resolution, a sampling rate of 1 kHz, and a proprietary processing platform operated through the EMG Analyzer software. For the placement of the electromyography sensors, the guidelines and recommendations provided by SENIAM (Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles) were followed for individual muscle locations on the upper trapezius, middle deltoid, long head of the triceps brachii, and both the long and short heads of the biceps brachii. General recommendations were followed for the pectoralis major, latissimus dorsi, and the radial extensors and flexors of the wrist. Muscle electrical activity was acquired over 15 seconds of contraction followed by one minute of recovery between tests, as per the methodology described by Stegeman, D., and Hermens, H. (2007).

A Seca brand stadiometer and measuring tape were used to assess height and measure lengths and circumferences of the upper limb. Body weight was measured using a Tanita HD314 digital scale. The Jamar hydraulic dynamometer was used to evaluate the prehensile or gripping force. For calculating the Body Mass Index (BMI), the 2023 World Health Organization (WHO) classification was used. The anthropometric measurements evaluated for the present study consisted of:

- Shoulder Perimeter Measurement (PAA): This measurement was taken from the right medial deltoid to the same point on the left side, using the measuring tape to form the ellipse corresponding to this path.

- Arm Length (LADD/LADI): This measurement was taken from the acromion to the tip of the index finger, with the elbow fully extended.
- Horizontal Grip (AHD/AHI): This measurement corresponds to the distance from the thumb's tip to the little finger's tip.
- Vertical Grip (AVD/AVI): This measurement corresponds to the distance from the base of the wrist to the tip of the middle finger.

The electromyographic activity during the free throw was evaluated on the court with each athlete's sports equipment and consisted of 15 shots from the regulation free throw line. These were performed continuously: an assistant collected the ball after each shot and passed it back to the athlete for the next throw, avoiding any external electromyographic recordings unrelated to the free throw.

After measuring the muscle's electrical activity isometrically and dynamically, the process continued with estimating muscle contraction through maximum voluntary contraction. For this purpose, the obtained electromyography signal was rectified, and a Root Mean Square (RMS) analysis was performed using a 200 ms moving window. Subsequently, the maximum value of the RMS signal was determined, and the electromyographic signal of the dynamic gesture, after RMS processing, was normalized to the signal obtained during the isometric test. Using the obtained and normalized signal according to maximum voluntary contraction, the mean of the signal and the maximum values obtained during the throwing gesture were estimated.

Ethical Considerations

The technical, scientific and administrative standards for health research were established in accordance with the provisions of Colombian law. this study was considered to have minimal risk. This classification means that the anticipated risks to participants are not more significant (considering both probability and magnitude) than those encountered daily or during routine physical or psychological examinations. When conducting the tests, participants were informed of the process to be undertaken, and authorized their participation by signing the informed consent form. This research was endorsed by the ethics committee of the Fundación Universitaria del Área Andina, as evidenced by the approval record dated April 27, 2022.

Statistical Analysis

The data collected was analyzed using descriptive statistics through JASP software version 0.16, developed by the University of Amsterdam. The values presented correspond to muscle activation data normalized using the Maximum Voluntary Contraction (MVC) technique. Muscle fatigue analysis was conducted using the analysis of the mean and median of the frequency spectrum using the Fast Fourier Transform (FFT). The normal distribution of the data was verified using the Shapiro-Wilk test. Parametric and non-parametric tests for related samples and effect size measurements were used to compare the fatigue index obtained within the isometric and dynamic tests. Due to the non-fulfillment of the assumptions of normality, Spearman's rank correlation was used for the analysis of associations between variables, with correlation strengths classified as follows: < 0.2 very low, < 0.4 low, < 0.6 moderate, < 0.8 good, and > 0.8 high (Salkind, 1999). Athletes were divided into clusters to identify characteristics in similar data (natural groupings) and subsequently to extract patterns that characterize one or more profiles.

For this purpose, the programming software R (R Statistics, version 4.0.5, Inc, Colorado, USA) was used with the package "FactoMineR." The Hopkins statistic was used to identify the existence of grouping tendency of the subjects; using unsupervised machine learning algorithms, the athletes were divided into groups or clusters according to the similarity in some characteristics. The data from the clusters were analyzed using the ANOVA test to show the equality of variances with Levene's test to determine the differences between the profiles generated. Omega squared (ω^2) was used to report the magnitude of differences, assuming < 0.01, 0.01, 0.06, and 0.14 as irrelevant, small, medium, and large effect sizes, respectively (Goss-Sampson, 2018). A significance level of $p < 0.05$ was considered. In addition, a multivariate analysis was carried out through Principal Component Analysis (PCA). PCA allows the classification of phenotypic variation into independent systems of correlated traits. This technique makes identifying the main directions of variation in the data possible and reducing its complexity without losing much relevant information. For this analysis, the variables were grouped into four groups: anthropometry, average muscle activation normalized by MVC, maximum muscle contraction normalized by MVC, isometric muscle fatigue, and dynamic muscle fatigue.

Results

Anthropometric Characteristics

Concerning the population evaluated and their anthropometric characteristics, three of the athletes were found to be left-handed. Concerning BMI, 29.17% were found to be overweight, 6.25% were found to be type I obese, and 2.08% were found to be underweight. Other anthropometric characteristics can be seen in Table 1.

Table 1. Anthropometric Characteristics and Dynamometry of Athletes.

Variable	Group	X (S)	Min - Max	p (df/46)	d
Size (m)	M	1.64 ± 0.06	1.54 - 1.80	<0.001	-2.285
	H	1.79 ± 0.08	1.65 - 1.98		
Body Mass (kg)	M	62.15 Me	47.20 - 79.70	<0.001	-0.747
	H	77.75 Me	57.80 - 124.70		
IMC (kg/m2)	M	23.47 ± 3.45	18.40 - 31.20	0.004	-0.869
	H	24.59 ± 3.21	19.80 - 34.70		
L_AD_D	M	74.31 ± 3.76	68.00 - 82.50	<0.001	-1.758
	H	81.75 ± 4.66	73.50 - 90.00		
L_AD_I	M	73.98 ± 3.40	69.00 - 81.50	<0.001	-1.826
	H	81.52 ± 4.75	73.00 - 90.00		
P_H	M	33.25 ± 1.69	29.50 - 36.00	<0.001	-2.568
	H	37.50 ± 1.61	34.00 - 40.00		
P_MDM_D	M	17.66 ± 1.03	15.00 - 19.50	<0.001	-2.062
	H	19.95 ± 1.17	17.50 - 22.00		
P_MDM_I	M	17.65 ± 0.85	16.00 - 19.00	<0.001	-2.180
	H	19.93 ± 1.21	18.00 - 22.00		
P_DIDP_D	M	19.52 ± 1.28	17.00 - 22.00	<0.001	-1.883
	H	22.20 ± 1.55	19.00 - 26.00		
APDMP	M	19.52 ± 1.23	17.00 - 22.50	<0.001	-1.882
	H	22.22 ± 1.61	19.00 - 26.00		
DIN_M_DER	M	26.38 ± 5.13	18.60 - 39.30	<0.001	-1.993
	H	39.90 ± 8.10	24.00 - 55.00		
DIN_M_IZQ	M	24.29 ± 5.24	16.00 - 33.30	<0.001	-2.110
	H	37.97 ± 7.52	22.00 - 53.30		

Note: M: Male; F: Female; BMI: Body Mass Index; L_AD_D: Acromion to right middle finger length; L_AD_I: Acromion to left middle finger length; P_H: Shoulder circumference; P_MDM_D: Carpal tunnel to proper middle finger circumference grip; P_MDM_I: Carpal tunnel to left middle finger circumference grip; P_P_ID: Little finger to right thumb circumference grip; P_DIDP_I: Little finger to right thumb circumference grip; P_DIDP_I: Little finger to left thumb circumference grip; P_DIDP_I: Little finger to left thumb circumference grip; Little finger to left thumb perimeter grip; DIN_M_DER: Right upper limb dynamometry; DIN_M_IZQ: Left upper limb dynamometry; Me: Median (does not meet the assumption of normality); †: Mann-Whitney U; df: Degrees of freedom; d: Effect size by Cohen's D and nonparametric by biserial correlation by ranks.

Muscle Activation Characteristics during Free-throw Shooting

The maximum voluntary contraction (MVC) performed by the athletes had a heterogeneous behavior in the different muscles, which can be observed in Table 2.

Table 2. Electromyographic Behavior during Launching.

Muscle	MVC MAX				MVC MEAN			
	X (S)	CV	Min	Max	X (S)	CV	Min	Max
FCR	63 ± 25	0.4	19	99	7 ± 4	0.549	2	26
Tri	60 ± 20	0.331	28	97	6 ± 3	0.46	0	12
Bic	41 ± 21	0.501	11	97	5 ± 3	0.64	1	15
TraS	52 ± 18	0.344	18	92	9 ± 5	0.617	3	38
PecM	43 ± 24	0.562	6	98	6 ± 4	0.672	1	20
DelM	66 ± 14	0.22	36	100	10 ± 4	0.466	5	33
DorA	61 ± 24	0.393	21	99	11 ± 8	0.758	0	39
ECR	41 ± 18	0.446	10	93	6 ± 3	0.501	0	16

Note: FCR: Flexor Carpo Radialis; Tri: Triceps; Bic: Biceps; TraS: Upper Trapezius; PecM: Pectoralis Major; DelM: Medial Deltoid; DorA: Llatissimus Dorsi; and ECR: Extensor Carpo Radialis.

Muscle Fatigue Analysis during Isometric and Dynamic Tests

According to the fatigue component analysis, a higher fatigue index was observed in dynamic tests compared to isometric tests. Additionally, the medial deltoid was the only muscle that did not show significant changes between tests (see Table 3).

Table 3. Fatigue Index in Dynamic and Static Tests Performed on Basketball Athletes.

Muscle	Fatigue	X(S)	CV	Min	Max	p-value	Cohen's d
Bic	Dynamic	12.25 ± 5.59	0.46	5.67	43.84	< 0.001	1.087
	Isometric	7.37 ± 3.01	0.41	1.42	16.49		
DelM	Dynamic	10.82 ± 2.05	0.19	7.53	16.50	0.176	0.278
	Isometric	10.15 ± 2.77	0.27	5.61	16.15		
DorA	Dynamic	17.48 ± 7.83	0.45	6.81	50.07	< 0.001	1.229
	Isometric	10.35 ± 2.44	0.24	6.08	16.04		
ECR	Dynamic	21.96 ± 7.23	0.33	11.23	48.15	< 0.001	1.382
	Isometric	14.21 ± 3.26	0.23	6.87	21.28		
FCR	Dynamic	20.85 ± 5.74	0.28	12.43	34.67	< 0.001	1.304
	Isometric	13.72 ± 5.18	0.38	1.30	24.98		
PecM	Dynamic	11.86 ± 5.54	0.47	3.26	40.57	< 0.001	0.919
	Isometric	7.71 ± 3.19	0.41	1.35	18.55		
TraS	Dynamic	7.99 ± 1.91	0.24	4.00	15.05	< 0.001	0.765
	Isometric	6.29 ± 2.49	0.40	0.81	11.27		
Tri	Dynamic	17.86 ± 4.87	0.27	10.02	29.48	< 0.001	1.935
	Isometric	9.68 ± 3.47	0.36	2.93	19.33		

Association between Study Variables

Analyses of the association between anthropometric variables and EMG recordings show some significant inverse associations. As can be seen in Figure 1, the significant findings are detailed. Associations that were not statistically significant ($p < 0.05$) and variables that obtained low and very low correlations ($\rho < 0.4$) were intentionally excluded. The inverse associations between anthropometric measurements and body mass and the EMG recordings of specific muscles stand out, i.e., the greater the weight or height of the subjects, the lower the EMG recordings.

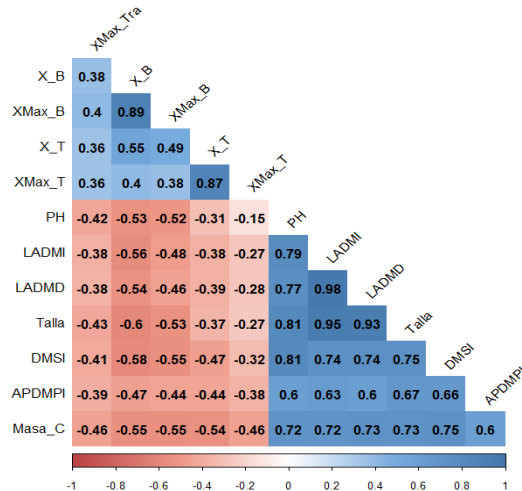


Figure 1. Association between Anthropometric Variables and EMG.

Note: The blue shaded area indicates positive correlations, and the pink area indicates inverse correlations. The higher the intensity of the color, the higher the value of the association. X_B: Mean biceps; XMax_B: Mean maximum biceps; X_T: Mean triceps; XMax_T: Mean maximum triceps; PH: Shoulder circumference; LADMI: Length acromion to left middle finger; LADMD: Length acromion to right middle finger; DMSI: Dynamometry of left upper limb; APDMPI: Grip perimeter from tip of little finger to left thumb; Mass C: Body mass.

Exploring Profiles Using Hierarchical Clustering

The Hopkins statistic value of 0.33 confirmed the presence of a clustering tendency among the subjects. The internal validation using the clValid tool suggested hierarchical clustering methods, and the number of clusters determined by the NbClust algorithm was three, using the Ward.D2 method. Three profiles were identified as clusters, as shown in the dendrogram illustrated in Figure 2. Cluster 1: Comprises 22 athletes, Cluster 2: Contains 16 athletes, and Cluster 3: Consists of 10 athletes.

The profiles generated through hierarchical analysis revealed significant differences primarily in anthropometric variables, while the electromyographic variables showed little difference among the groups. Despite the limited variation in electromyographic variables, the analysis successfully recognized differences between the identified profiles, allowing for the grouping of athletes with sufficient internal validity, as shown in Table 4. As observed, Profile 3 (Cluster 3), which is composed of athletes with larger dimensions in anthropometric variables and higher grip strength (as measured by upper limb dynamometry), consists exclusively of male athletes (n=10). In descending order of anthropometric values, Profile 2 (Cluster 2) is composed of 12 men and four women. Finally, Profile 1 (Cluster 1) consists of athletes with the smallest anthropometric values and grip strength, comprising 20 women and two men.

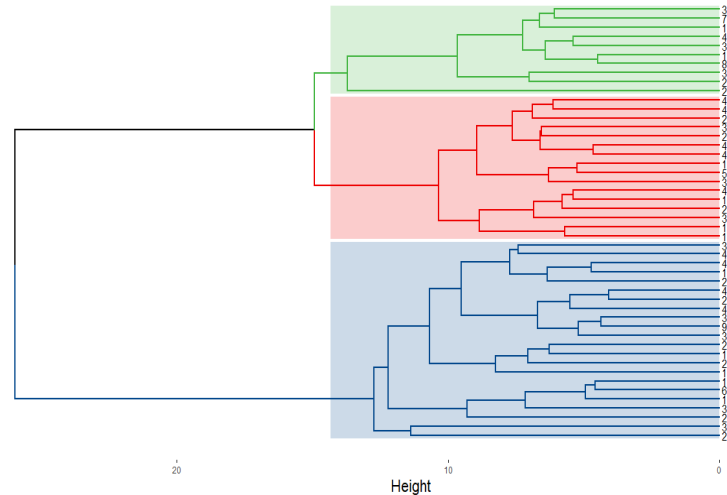


Figure 2. A Dendrogram for Profiling Basketball Players Based on Clustering.

Note: The blue shaded area represents Cluster 1, red represents Cluster 2, and green represents Cluster 3.

Regarding fatigue indices, athletes of Profile 3 present more significant isometric fatigue in the dorsal and triceps muscles (taller athletes) than the other profiles. In contrast, more significant dynamic fatigue was observed in the dorsal and trapezius muscles in the athletes of Profile 2. Regarding the Maximum Voluntary Contraction (MVC), evidence shows that there was greater neuromuscular activation in athletes from Profile 1, characterized by shorter stature and smaller measurements in anthropometric variables.

Table 4. Comparison of Average Scores by Clusters.

Variable	Cluster 1 (n = 22)	Cluster 2 (n = 16)	Cluster 3 (n = 10)	F(2, 45)	ω^2	Post-hoc
<i>Anthropometry</i>						
Size _(m)	1.63±0.05	1.75±0.06	1.85±0.06	69.26**	0.740	3>2 & 1, 2>1 [†]
Mass C _(kg)	61.43±8.81	75.38±12.29	85.96±14.42	17.78**	0.411	3>2 & 1, 2>1 [†]
LADMD _(cm)	73.41±2.92	79.66±3.15	85.60±2.87	60.80**	0.714	3>2 & 1, 2>1 [†]
LADMI _(cm)	73.14±2.62	79.19±3.02	85.60±2.76	71.96**	0.747	3>2 & 1, 2>1 [†]
PH _(cm)	33.16±1.71	36.63±1.83	38.25±1.30	38.19**	0.608	3>2 & 1, 2>1 [†]
APTCDD _(cm)	17.59±1.09	19.22±0.93	20.85±0.75	40.45**	0.622	3>2 & 1, 2>1 [†]
APTCDI _(cm)	17.63±0.94	19.09±0.82	20.90±0.97	46.19**	0.653	3>2 & 1, 2>1 [†]
APDMPD _(cm)	19.50±1.40	21.19±1.08	23.35±1.42	30.93**	0.555	3>2 & 1, 2>1 [†]
APDMPI _(cm)	19.66±1.51	21.03±1.19	23.30±1.57	22.55**	0.473	3>2 & 1, 2>1 [†]
<i>Dynamometry</i>						
DMSD _(kg)	25.60±4.16	36.11±7.82	44.98±5.12	41.49**	0.628	3>2 & 1, 2>1 [†]
DMSI _(kg)	23.99±5.38	34.03±7.60	42.22±5.23	32.96**	0.571	3>2 & 1, 2>1 [†]
<i>EMG</i>						
FIsOD	9.94±2.21	9.77±2.30	12.20±2.43	4.12*	0.115	3>2 & 1 [†]
FIsOT	10.37±2.52	7.63±3.01	11.42±4.60	5.28*	0.151	3>2 & 1>2 [†]
FDinD	17.99±6.07	20.34±9.99	11.77±4.03	4.30*	0.121	2>3 [†]
FDinTra	7.76±1.67	8.99±2.22	6.88±1.06	4.67*	0.133	2>3 [†]
X_T _(MVC)	6.95±2.60	4.52±1.91	4.35±2.13	7.04*	0.201	1>2 & 3 [†]
X_B _(MVC)	6.55±3.27	3.28±1.07	2.63±1.62	H(2) 18.30**	0.329	1>2 & 3 [†]

Note: Mass C: Body mass; LADMD: Acromion to right middle finger length; LADMI: Acromion to left middle finger length; PH: Shoulder girth; APTCDD: Carpal tunnel perimeter grip to right middle finger; APTCDI: Carpal tunnel perimeter grip to left middle finger; APDMPD: Tip of little finger to right thumb perimeter grip; APDMPDI: Tip of little finger to left thumb perimeter grip; DMSD: Right upper limb dynamometry; DMSI: Left upper limb dynamometry; FIsoD: Dorsal isometric fatigue; FIsoT: Triceps isometric fatigue; FDinD: Dorsal dynamic fatigue; FDinTra: Trapezius dynamic fatigue; X_T: Triceps average; X_B: Biceps average. **: $p < .001$; *: $p < .05$; † Significant differences between groups (Pos Hoc scheffe $p < .05$); ‡: Dunn nonparametric; F: Anova statistic when Levene's test indicates equality of variances $p > .05$; H: Kruskal-Wallis nonparametric statistic.

PCA Analysis

Through the use of Principal Component Analysis (PCA), variables were grouped into categories including anthropometry, average normalized muscle activation by MVC (mean_mvc), maximum normalized muscle activation by MVC (max_mvc), isometric fatigue (fiso), and dynamic fatigue (fdin). Within each category, the contribution level of each variable was determined. This contribution is shown in Figure 3.

Subsequently, the grouping analysis was performed considering the categories of playing positions.

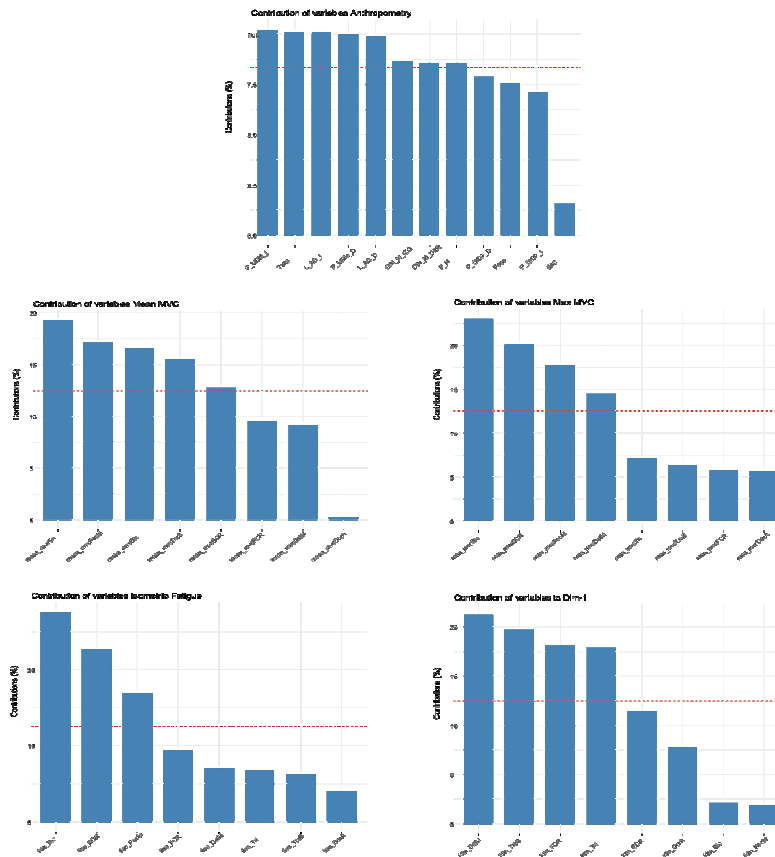


Figure 3. Variable Contribution Graph by Category.

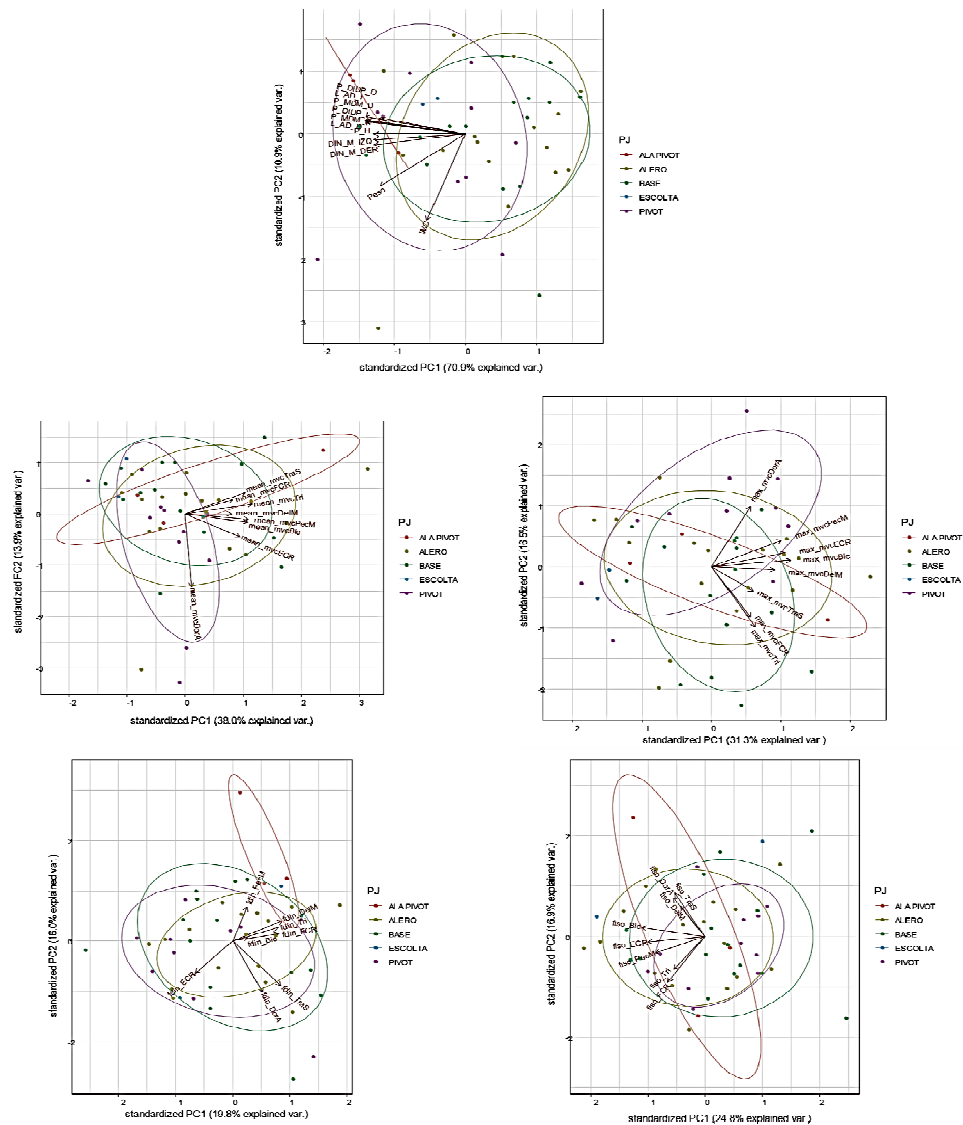


Figure 4. The behavior of the Variables by Cluster According to the Playing Position Graph.

Discussion

The objectives of this research were clearly defined as follows: to determine Anthropometric and Electromyographic Characteristics in the free throw shooting gesture along with possible associations between the study variables and to explore athlete profiles using unsupervised machine learning algorithms in college-level basketball players.

Body Composition and Anthropometric Characteristics

Body mass index (BMI) is widely used as a simple indicator of weight-for-height ratio in adults to identify overweight individuals and obesity. According to the World Health Organization (WHO, 2022), being overweight is defined as a BMI equal to or greater than 25, and obesity as a BMI equal to or greater than 30. Even though the population evaluated in this study consists of athletes with regular sports practice, more than 30% show tendencies to be overweight or obese. This finding could be aligned with the research of Bustamante et al. (2017), who studied 36 adolescent basketball players and found that the valuable time of each training session impacts the athlete's BMI. Their results indicated that groups of athletes with higher average training volume showed improved health and reduced BMI compared to the beginning of the season, in contrast to athletes with lower training volume. This suggests that some college athletes in this study may not meet the minimum physical activity recommendations, and their eating habits may be unhealthy, contributing to increased BMI.

Barut et al. (2008) suggest that anthropometric measurements of hand and grip strength may be sport and gender dependent. They found significant differences in these variables when comparing basketball, volleyball, and handball athletes between nine and 18 years of age. Their study reports average measurements of 170.43 mm and 171.40 mm for right- and left-hand length, respectively, in 145 basketball players. These measures differ from the results obtained in the present study. Similarly, Pizzigalli et al. (2017) suggest that prehensile strength in basketball athletes is directly related to age and sports level. They report a right prehensile strength of 38.8 ± 7.7 kg and a left prehensile strength of 38.5 ± 8.2 kg for the 19- to 20-year-old Italian female athletes, similar to those found in the present study according to the mean age of the population evaluated.

Electromyographic Behavior in Launching

This study highlights that the medial deltoid, longissimus dorsi, triceps, and flexor radialis longus muscles are the primary muscles involved in throwing in basketball. However, a high coefficient of variation is observed in the activation normalized by maximal voluntary contraction (MVC) in latissimus dorsi and pectoralis major. This suggests that these muscles are prone to increased fatigue and exhibit low endurance despite their high demand in sports practice.

The latissimus dorsi muscle is crucial in extending the glenohumeral and scapulothoracic joints. In addition, it collaborates in internal rotation and acts as an adductor muscle. It works with the pectoralis major to generate resistance in abduction and limit scapulothoracic flexion (Kapandji, 2006). Comel et al. (2018) highlight the pectoralis as a stabilizing shoulder joint muscle connecting the upper limb to the thorax. Weakness in these muscles can lead to recruitment and overload of other muscles, such as the trapezius, during functional activities.

This underscores the need to strengthen and focus training on these muscles, especially given their high coefficient of variation. Strength training is pivotal in helping players adapt their neuromuscular system to increase the force they can produce, thus improving the nervous response and optimizing the muscle contraction process (Bompa & Haff, 2009). Speed and synchronization of nerve signals improve with maximal strength training, contributing to progress in muscular endurance (Kraemer & Looney, 2012).

This study also highlights the increase in the fatigue index in dynamic tests compared to isometric tests, which is related to the high weekly training volume. Tavares et al. (2017) suggest that the density of intensive training programs can limit recovery, leading to muscle fatigue and affecting performance. Basketball athletes exposed to high-load/speed contraction training can experience fatigue and decreased performance (Kraemer & Looney, 2012). Therefore, the study emphasizes the importance of considering various factors to avoid athletes' overload and fatigue, as Argus et al. (2010) pointed out in rugby athletes.

In team sports such as basketball, continuous eccentric actions, such as changing direction or propelling a ball, generate a stretch-shortening cycle and can cause muscle fatigue due to the disruption of cross-bridges and the disruption of contractile and structural proteins in the muscle cell (Farthing & Chilibeck, 2003; Fridén & Lieber, 2001).

Association between Study Variables and the Exploration of Profiles

The association analyses observed significant inverse correlations between anthropometric variables and electromyographic (EMG) activity of the trapezius, triceps, and biceps muscles. Specifically, athletes with greater dimensions, lengths, and perimeters in their extremities showed less muscular activity when performing the throwing gesture. This suggests that the relationship between body size, body mass, and limb length influences the strength required to execute the throw with a relatively lightweight sports implement. This relationship also aligns with human muscle growth and development processes in humans (Herzog et al., 2011). Alternatively, athletes with shorter stature and limb lengths exhibited higher muscle activity than their peers, supporting evidence of the relationship between muscle length and force generation (Winters et al., 1993; Nuzzo, 2023). This finding suggests that shorter athletes may need more muscular effort to achieve similar performance levels as their larger counterparts, possibly due to less mechanical advantage and smaller muscle mass.

Three distinct clusters were identified in the exploration of profiles using hierarchical analysis. Cluster 3 primarily comprised men who were more prominent in size, with greater body mass, anthropometric lengths, circumferences, and strength as measured by dynamometry. Following Cluster 3, Cluster 2 was primarily composed of men, and Cluster 1 predominantly consisted of women. These results suggest that the fatigue indices and EMG recordings show variability in all athletes and do not allow for the formation of distinctive groups (clusters) based on fatigue indices or EMG activity. This finding is consistent with previous research that found no significant sex differences in neuromuscular activation in certain types of contraction (Hunter & Enoka, 2001; Kavanagh et al., 2020).

These findings highlight the significant influence of sex on anthropometric variables conditioned by diverse hormonal environments, as previously confirmed in studies (Handelsman et al., 2018). Although anthropometric variables are relevant for profiling basketball players, future research needs to investigate the relationship between these variables and performance and sports success.

PCA Analysis

According to Figure 3, the variables that contribute the most to this study from the category of anthropometry are the grip perimeter from the carpal tunnel to the left and right middle fingers and, in terms of

height, the length from the acromion to the left and right middle fingers. This is directly related to the lever arms and the movement dynamics during the free throw and for gripping and directing the ball. This finding agrees with that investigated by Koley (2010), who found strong correlations between grip strength and several anthropometric traits, such as length, size, and muscle activation, in improving basketball shooting or throwing. Additionally, he reported that the longer the fingers, the better the shooting or throwing accuracy in the game. Therefore, some researchers have examined a series of factors and anthropometric variables that explain this issue, as done by Fallahi (2011), who demonstrated that in basketball, various movements depend on the continuous use of muscles such as the wrist and finger flexors since they are of great importance in catching, holding, shooting, and throwing the ball.

Previous studies indicate that body fat percentage is significantly associated with speed and agility concerning ball grip. In contrast, hand grip strength and weight status are associated with upper extremity explosive strength. Changes in body composition, years of experience, and weight status influenced players' physical performance and motor skills, especially speed, agility, and explosive strength of the upper limbs (Rinaldo, 2020).

At the level of average muscle activation, the triceps, pectoralis major, biceps, and upper trapezius make the most significant contributions. This is particularly important in athletic throwing because, during that phase, elastic energy storage will be released later in the acceleration phase (Roach, 2012; Roach et al., 2013). During the arming phase, EMG activity of the trapezius and pectoralis major helps stabilize the scapula and thus generate adequate torque for subsequent humeral internal rotation (Paine, 1993; Digiovine, 1992; Hirashima, 2002). In addition, the EMG pattern of biceps activation and deactivation is vital in preventing and allowing centrifugal forces to extend the elbow, thus facilitating adequate elastic energy storage during the arming phase and the generation of rapid elbow extension during the acceleration phase (Roach et al., 2013; Werner, 1993). This is relevant because, as Gowan et al. (1987) reported, expert athletes have significantly higher activation of the pectoralis major muscle, while amateurs show significant biceps brachii activation during the entire throwing motion. In addition, a selective deactivation of the biceps brachii by the experts during acceleration is observed, with no significant differences between the groups for the trapezius muscle, showing, for this study, a possible selection for the group of athletes.

A study by Pakosz et al. (2021) evaluated muscle activation time and free throw effectiveness in basketball. It concluded that significant differences were found in muscle activation in novice, intermediate, and expert subjects, with the triceps brachii showing a significant variation in the coefficient of variation and efficiency of 81%. The activation time of the arm muscles during a free throw and its variations change according to the training experience of basketball players.

While at the level of maximum muscle activation, the most outstanding contributions are evidenced by the biceps, wrist extensor, pectoralis major, and medial deltoid. During overhead throwing, high rotator cuff muscle activity is generated to help resist the high distraction forces of the shoulder. During arm preparation, the maximal rotator cuff activity is 49% to 99% of a maximal voluntary isometric contraction; during arm deceleration, it is 37% to 84% (Escamilla et al., 2009).

Maximal scapular muscle activity is also high during the arm preparation and deceleration phases of throwing, with maximal serratus anterior activity of 69% to 106%, maximal upper, middle, and lower trapezius activity of 51% to 78%, maximal rhomboid activity of 41% to 45% and maximal levator scapulae activity of 33% to 72%. In addition, the maximum activity of the serratus anterior was approximately 60% during throws (Escamilla, 2009).

From the fatigue analysis, at the isometric level, the muscles with the most significant contribution were the biceps, hand extensor, and pectoralis major. These EMG frequency responses are due to increased fatigue, resulting in increased muscle activation to meet force demand and reduced action potential conduction velocity. During voluntary contractions, the timing and coherence of motor units are often quantified simultaneously to provide complementary information about the adjustments made by the nervous system (NS) adjustments during various tasks (Dartnall, 2008). These EMG frequency responses are due to increased fatigue, resulting in increased muscle activation to meet force demand and reduced action potential conduction velocity. However, regarding the muscles of the upper extremities, changes have been observed in the synchronization of motor units during isometric contractions compared to when forces are exerted in different directions. For example, Semmler (2002) suggests that isometric contractions alter the synaptic input sent to the motor units involved. The above is a highly discussed and accepted aspect by different authors since it is a commonly accepted opinion that certain types of exercise, such as fatigue or strength training, can improve the correlated activity of motor units (Gandevia 2001; Semmler 2002; Kidgell et al., 2006).

Compared to that found by Clough (1968), most measurements of motor unit synchronization strength are made in the muscles of the hand or wrist, as these have corticospinal solid projections to motor neurons (Phillips, 1964). The biceps brachii muscle's corticospinal inputs to motor neurons are generally weaker than hand muscles (Palmer, 1992), reflected in reduced synchrony in proximal muscles (Kim et al., 2001). However, alterations in recurrent inhibition, mainly directed toward low-threshold motor units associated with fatigue

(Katz & Pierrot-Deseilligny, 1999), could induce changes in inhibitory inputs standard to motor neurons at the spinal level after exercise. The effects of muscle damage result in a shift in the length-tension relationship toward longer optimal muscle lengths for maximum force generation, an increase in passive tension throughout the muscle, and a reduction in maximum force output (Proske & Allen, 2005), leading to a series of physiological and mechanical events that cause muscle damage (such as fatigue) from exercise and influence the neural inputs responsible for the correlated discharge of the motor unit.

The medial deltoid, upper trapezius, hand flexor, and triceps were the muscles that contributed the most to the dynamic component. From the analysis of the clustering graph by categories according to playing position, athletes in the power forward position are the only ones who exhibit behavior different from the other positions. This is because, in this position, they must secure rebounds on both the defensive and offensive sides, which contributes to controlling ball possession. Additionally, they block shots from the opposing team, challenge opponents trying to penetrate, and protect the painted area, among other actions that require high physical demands.

The present investigation has limitations, including a wide age range for a small sample of men and women. Therefore, future studies with a larger population sample are suggested to enable comparisons between different age groups. At the same time, athletes from different competitive levels should be included.

Conclusions

The present study showed that of the 24 participants in the study, the majority are overweight, Cluster 3 was characterized by being made up only of men, having anthropometric characteristics superior to the other clusters specifically in size, lengths and body perimeters such as grip strength, greater isometric fatigue in the dorsal and triceps muscles for taller athletes), compared to the other profiles. On the contrary, greater dynamic fatigue was observed in the dorsal and trapezius muscles in the athletes of profile 2. Regarding the MCV, greater neuromuscular activation was evident in the athletes of profile 1 (athletes of shorter height and record in the anthropometric variables evaluated) Likewise, a higher fatigue index was established in the dynamic tests than in the isometric tests. Through these results and their analysis, coaches and athletes will have a bibliographic basis to discuss the inclusion of strengthening exercises for under-trained muscles that play a significant role in highly demanding gestures. Their efforts in changing training programs can generate benefits around performance during competitions and prevent upper extremity injuries.

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Conflict of Interest

The authors report no conflict of interest in developing this research.

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