

Examining muscular activity in the Zeppelin throwing gesture among rugby players in Bogotá

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Abstract

Rugby, characterized by evasion and contact, relies on the strategic use of strength and speed to navigate the field, and score a touchdown. In the dynamics of the sport, a critical maneuver involves executing a lateral pass on the fly to a teammate action known as the Zeppelin throw. This study aimed to analyze the muscular behavior exhibited during the Zeppelin throwing gesture among rugby players from Bogotá. For this study, we enlisted 12 athletes affiliated with the rugby league in Bogotá, with an average age of 26.3 ± 5.5 years, a sports practice duration of 44 months, and a training frequency of three times per week. The BTS FREEEMG1000 equipment was used to record the electromyographic signal. In addition, an isometric test and a dynamic test were used for the recording of the electromyographic signal and the analysis of the contraction by MVC and the estimation of fatigue. It was observed that the flexor carpi radialis, triceps, biceps, pectoralis major and latissimus dorsi muscles present an activation percentage greater than or equal to 60% during the Zeppelin throw. On the other hand, the fatigue index during the dynamic test was higher compared to the isometric test with $p < 0.005$ and d-Cohen > 0.69 except for the flexor carpi radialis, this muscle being the one that presented the highest fatigue index. The study used Principal Component Analysis (PCA) to analyze muscle behavior in the Zeppelin throw. This provides a clearer understanding of the key variables that influence the execution of this technical gesture, including anthropometric characteristics and muscle activation. In addition, differences in muscle activation and fatigue were observed between different rugby playing positions.

Keywords: Rugby; Surface electromyography; Muscle fatigue; Muscle strength.

Introduction

Rugby is an evasion and contact sport involving two modes, with the non-contact team mode being the exception. Each team is composed of fifteen players and focuses on the use of force to advance up the field with the ball and score points. The main objective is to outscore the opposing team in terms of points. The duration of a rugby match should not exceed 80 minutes, plus injury time (World Rugby, 2015).

Within the dynamics of the sport, a passing technique known as the "zeppelin throw" is employed. In this pass, the ball is carried with both hands in front of the player, gripping it firmly with both hands. To execute the movement, a balance point is sought in the run by increasing the player's base of support by lengthening the last step before the pass. The forward leg serves as support and is always the leg opposite the side where the ball will be thrown. The player's hands are separated to release the ball, and the fingers must be well stretched to accompany the ball as it is thrown. Simultaneously, the receiving teammate, who has moved slightly backwards, extends his arms in front of him to receive the ball sent at half height (Navarro-Zurita, 2017).

In the zeppelin throw, the player must turn the ball so that its major axis is approximately 30 degrees to the horizontal plane. During the passing action, the upper hand is used to provide power and give the ball a spinning motion, while the lower hand is used to provide stability and direction (World Rugby, 2022). Considering the characteristics of the movement, which involve elbow flexion-extension, shoulder abduction-adduction and thumb flexion-extension, as well as ball spin dynamics and the explosiveness of the throw, a metabolic and functional response of the fast twitch muscle fibers is generated at the muscular level. From a biomechanical perspective, the sporting gesture involves a combination of actual glenohumeral rotation, trunk hyperextension and scapulothoracic movement. Near the moment of maximal external rotation of the shoulder, the shoulder and elbow musculature contract eccentrically to produce an internal rotational torque of the shoulder and a varus torque of the elbow (Fleisig et al., 1996; Hamilton et al., 2014).

In skeletal muscle, three types of muscle fibers have been differentiated according to their metabolic and functional properties. They have been classified as fast glycolytic fibers, fast glycolytic-oxidative fibers, and

slow oxidative fibers. Fast-acting fibers have high activity in the sarcoplasmic reticulum and myofibril to generate energy in the form of ATP, while slow oxidative fibers have low ATPase activity. It has been observed that in physical exercises where isometric and concentric movements are generated, fast-acting fibers develop fast contractile moments, but at the same time experience an increase in metabolic acidosis, a decrease in pH and an increase in fatigue levels. On the other hand, slow fibers present a low shortening velocity, which allows them to have a high resistance to fatigue (Sundberg & Fitts, 2019; Tornero-Aguilera et al., 2022).

On the other hand, surface electromyography (EMG) is a process that records the electrical activity of muscle contraction using electrodes. It generates a small electric current and converts this signal into graphics, sounds and numerical values. It can be performed during the execution of functional patterns such as walking, climbing, throwing objects, among others. It is considered a non-invasive method whose electrodes, at present, do not require wires and are attached directly to the skin over the muscle at the motor point. In addition, they can use wireless systems to capture the muscle electrical signal and its subsequent processing and computational analysis (Krasnik et al., 2011). It is a useful tool for analyzing fatigue states at the neuromuscular level. Muscle fatigue manifests itself with symptoms such as the inability to maintain the desired force production, muscle tremors and localized pain. The effects of this fatigue are localized to the muscle or group of synergistic muscles performing the contraction. Halperin et al. (2015) and Bromberg (2020) explained this interrelationship by noting that, during a sustained contraction, the low frequency components of the EMG signal increase and, therefore, more energy of the EMG signal will be transmitted due to the low pass filtering effect.

Three explanations have been proposed to address the increase in amplitude and change in frequency of the EMG signal observed during sustained isometric contraction with constant force. These explanations include motor unit recruitment, motor unit synchronization, and changes in the conduction velocity of muscle fibers. To analyze the behavior in terms of frequency change, a power spectrum analysis model of the electromyography signal is proposed, which is represented by equation 1.

$$S_m(\omega, t, F) = R(\omega, d) \left[\sum_{i=1}^{p(F)} S_{ui}(\omega, t) + \sum_{i,j=1,i \neq j}^{q(F)} S_{uiuj}(\omega, t) \right]$$

where, t is the time, F the force, and $S_{ui}(\omega, t)$ corresponds to the density of the spectrum of a motor muscle fiber. $S_{uiuj}(\omega, t)$ is the cross-spectrum of power between motor muscle fibers, $R(\omega, d)$ equals the filtering function for the acquisition electrodes; p corresponds to the total number of motor muscle fibers composing the signal, q the number of motor muscle fibers correlated with the electrical depolarization and d the distance between the electrodes in a bipolar configuration.

Any modification in the waveform of the motor muscle fibers is reflected in the spectral analysis using the Fourier transform and, therefore, in the power density spectrum. The waveform would have a longer duration as the conduction velocity decreases during a sustained contraction, as the time required to travel the distance between electrodes would be longer. This would result in a simultaneous increase in the low-frequency components and a decrease in the high-frequency components. Because of these changes in frequency, several authors have proposed central tendency measures to analyze the electromyography signal, which are linearly related to the conduction velocity of the muscle fibers (Koutsos et al., 2016). It has been shown that mean and median frequency values decrease with time during a sustained contraction, as does force in a linear fashion in an isometric movement. These changes are directly related to the presence of muscle fatigue (Basmajian & De Luca, 2008).

Thongpanja et al. (2013) present how mean and median frequency values can be used as indices of muscle strength and fatigue. The median frequency can be determined by considering that this measure divides the signals into equal parts, so that:

$$\sum_{j=1}^{MDF} P_j = \sum_{j=MDF}^M P_j = \frac{1}{2} \sum_{j=1}^M P_j$$

Where P_j , is the EMG power spectrum at a frequency interval j and M is the length of the frequency interval.

On the other hand, the mean frequency can be calculated as the sum of the product of the EMG power spectrum and the frequency, divided by the sum total of the intensity of the spectrum and can be expressed as:

$$MNF = \frac{\sum_{j=1}^M f_j P_j}{\sum_{j=1}^M P_j}$$

Where f_j , is the frequency value in a frequency interval j (Thongpanja et al, 2013).

The frequency spectrum of the electromyographic (EMG) signal is a very sensitive indicator of muscle fatigue. The two main factors that cause this change are (1) decreases in motor unit discharge rates and (2) changes in the shapes of the motor unit action potentials that make up the EMG signal. Of these two factors, changes in the shape of the action potential are much more important and are caused primarily by decreases in the conduction velocities of the active fibers, although other factors are also important. Specifically, conduction velocities are greatly affected by intracellular pH and, therefore, the acidosis developed during intense exercise

causes compression of the EMG power spectrum toward lower frequencies. This compression is usually accompanied by a measure of central tendency for the power spectrum (Beck et al., 2014).

The present study aims to determine the behavior of muscle fatigue during the Zeppelin throwing gesture in rugby players from the city of Bogotá.

Materials & Methods

Participants

For the present study, 12 athletes from the rugby league of Bogotá participated, who met the following inclusion criteria: to be of legal age, to be linked to a sports club for at least the last 2 months, to practice specific sports at least 3 times a week, to sign an informed consent and assent form, and not to present alterations in their health condition at the time of the evaluation. Likewise, the following exclusion criteria were met people with musculoskeletal injuries in the upper limb during the last year and those who did not know the development of the sporting gestures to be evaluated were not included. The population evaluated was composed of 5 women and 7 men, with an average age of 26.3 ± 5.5 years, with a dominance of 75% right-handed and an average length of time in sports practice of 44 months, with a training frequency of 3 times a week.

Instruments

For the measurement of body composition, an OMRON scale and an Inbody Inlab digital measuring rod were used, together with anthropometric tapes for the measurement of length and perimeter variables. For the recording of the surface electromyography signal, 8-channel BTS FreeEmg 1000 equipment (BTS Bioengineering Corp) was used. This device is an IEEE 802.15.4 Wireless surface electromyograph with a resolution of 16 bits, an acquisition frequency of 1 kHz and a proprietary processing platform under EMG Analyzer software.

Procedure

Anthropometric Measurement

The anthropometric measurements evaluated for the present study consisted of:

- Shoulder circumference measurement (PAA): the measurement was taken from the right medial deltoid to the same point, generating with the tape measure the ellipse corresponding to this trajectory, passing through the left medial deltoid.
- Arm length (LADD/LADI): The distance from the acromion to the tip of the index finger was taken, with the elbow in full extension.
- Horizontal grip (AHD/AHI): This measurement corresponded to the distance from the tip of the thumb to the tip of the little finger.
- Vertical Grip (AVD/AVI): This measurement corresponded to the distance from the base of the wrist to the tip of the middle finger.

Maximum electromyographic signal evaluation

For the location of the electromyography sensors, the indications and recommendations given by SENIAM (Surface Electromyography for the Non-Invasive Assessment of Muscles) were followed for the location of individual muscles in: Upper trapezius, middle deltoid, triceps brachii (long head), biceps brachii (long and short head), and general recommendations were followed for: Pectoralis major, latissimus dorsi, and radial carpal extensors and flexors. The location of the evaluated muscles was performed as follows, and the acquisition of muscle electrical activity was developed during 15 seconds of contraction and 1 minute of recovery between tests.

- Extensor Carpo Radialis (ECR): the person was placed in a seated position, with the shoulder in neutral position and the elbow at 90°, the forearm in support, and the wrist in pronation. A load was placed on the wrist to generate extension movement without the possibility of generating angular displacement.
- Flexor Carpo Radialis (FCR): the person was placed in a seated position, with the shoulder in neutral position and the elbow at 90°, the forearm in support, and the wrist in supination. A load was generated on the wrist to generate flexion movement without the possibility of generating angular displacement.
- Triceps (Tri): the person was placed in a seated position, with the shoulder in full flexion, the elbow at 90°, and a grip load was generated in the wrist requesting elbow extension without generating angular displacement. Stabilization of trunk anterior rotation and shoulder extension was generated.
- Biceps (Bic): the person was placed in a seated position, with the shoulder in neutral position, the elbow at 90 degrees of flexion; a load was applied on the wrist indicating elbow flexion movement, but without generating angular displacement. Shoulder stabilization was generated to avoid shoulder elevation and trunk tilt.
- Upper Trapezius (TraS): the person was placed in bipedal position with shoulders at 0° of flexion, elbows in full extension and load in grip at the wrists, the participant was asked to raise the shoulders without generating vertical load displacement.

- Pectoralis major (PecM): the person was placed in bipedal position, with the shoulder in flexion of 90 degrees and full extension of the elbow, the arm was positioned in horizontal adduction of 0 degrees and a load was applied on the wrist in adduction movement.
- Medial Deltoid (DelM): the person was positioned in a seated position, with the shoulder at 90° of abduction, the elbow in full extension and the load was applied on the forearm to generate abduction movement without angular displacement.
- Latissimus dorsi (DorA): the person was placed in a seated position, with the arm fully extended, neutral position of the shoulder and the elbow in extension. A load was applied on the forearm for the intention of movement towards shoulder extension without angular displacement.

Evaluation of the electromyographic activity during the zeppelin throw.

With the electromyography probes positioned on the muscles, the athlete was asked to generate the ball throw continuously for 15 seconds. Muscle electrical activity data were captured and stored using EMG Analyzer software.

After measuring the isometric and dynamic muscle electrical activity, we proceeded to estimate the muscle contraction through the maximum voluntary contraction. For this purpose, the electromyography signal obtained was rectified and an RMS analysis was performed with a 200ms moving window. Subsequently, the maximum value of the signal with RMS was determined and the electromyographic signal of the dynamic gesture after processing with RMS was divided into that obtained in the isometric test. On the signal obtained and normalized according to the maximum voluntary contraction, the mean of the signal and the maximum values obtained during the throwing gesture were estimated.

Statistical analysis

The analysis of the data obtained was performed using R Studio software. The values presented correspond to the muscle activation data normalized by means of the MVC technique and the muscle fatigue analysis through the mean and median of the frequency spectrum by means of the fast Fourier transform. For the comparison of the fatigue index obtained in the isometric and dynamic test, the t-test for related samples was used to establish significant differences, and Cohen's test was used to determine the effect size. A significance level of $p < 0.05$ was maintained. Additionally, a multivariate analysis was carried out through Principal Component Analysis (PCA). PCA allows the classification of phenotypic variation into independent systems of correlated traits. By using this technique, it is possible to identify the main directions of variation in the data and reduce its complexity without losing much of the relevant information. This ability to summarize information in a few dimensions is essential for the interpretation and visualization of complex data. For this analysis, 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.

Ethical Considerations

According to Resolution 8430 of 1993 of the Ministry of Social Protection, which established the technical, scientific, and administrative norms for health research, this research was considered of minimal risk. By means of the protocol presented to the ethics committee of the Fundación Universitaria del Área Andina, the actions to be followed for risk mitigation and attention were determined. During the development of the tests, the participants were informed about the process to be developed, the benefits and risks. The participants authorized their participation by signing the informed consent form, safeguarding professional secrecy. The investigators undertook not to disclose the identity or background of the persons who, of their own free will, participated in the research. The present research was endorsed by the ethics committee of the Fundación Universitaria del Área Andina by means of the approval act of April 27, 2022.

Results

The population evaluated had the anthropometric characteristics shown in Table 1.

Table 1. Anthropometric characteristics of the population.

Variable	Mean	Std. Dev.	Coefficient of Variation
Height (cm)	167,583	8,174	0,049
Weigth (kg)	68,583	13,541	0,197
BMI (kg/m2)	24,500	3,943	0,161
LADD (cm)	74,683	5,005	0,067
LADI (cm)	74,592	5,045	0,068
PAA (cm)	42,625	9,364	0,220
AHD	20,625	1,196	0,058
AHI	20,492	1,393	0,068
AVD	17,567	0,907	0,052
AVI	17,500	0,903	0,052
DINAD (kg)	36,800	9,157	0,249
DINAI (kg)	35,925	8,954	0,249

Note: BMI=body mass index, LADD=Length of acromion to right finger, LADI=Length of acromion to left finger, PAA=perimeter of acromion to acromion, AHI=left horizontal grip, AVI=left vertical grip, AHD=right horizontal grip, AVD=right vertical grip, DINAD=right grip strength, DINAI=left grip strength.

Muscle activation during Zeppelin launch normalized by MVC.

After completing the process of measurement, data processing and statistical analysis, the analysis of muscle activation through normalization by MVC is presented. In this analysis, the results of the ball throwing test were normalized with respect to the values obtained in the isometric tests. These results are shown in Table 2.

Table 2. Analysis of muscle activation by means of maximum voluntary contraction.

Muscular Group	Value	Mean (%)	Typical Desv	Coefficient of variation	Mín. (%)	Max. (%)
Extensor Carpi Radialis	Media	11	5	0,43	6	16
	Máximo	48	19	0,39	29	67
Flexor Carpi Radialis	Media	13	6	0,48	7	19
	Máximo	66	25	0,37	41	91
Triceps	Media	21	22	1,06	1	43
	Máximo	77,1	17	0,99	60,1	94,1
Biceps	Media	17	7	0,42	10	24
	Máximo	63,2	25	0,57	38,2	88,2
Upper Trapezium	Media	14	9	0,64	5	23
	Máximo	57	34	0,6	23	91
Pectoralis major	Media	13	6	0,46	7	19
	Máximo	66	32	0,49	34	98
Medial Deltoid	Media	8	4	0,45	4	12
	Máximo	41	9	0,22	32	50
Latissimus Dorsi	Media	13	15	1,19	2	28
	Máximo	68	30	0,38	38	98

Muscle fatigue analysis during isometric and dynamic tests.

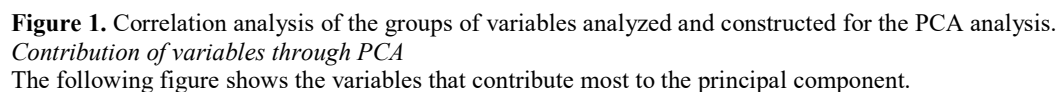
Through the spectral analysis developed, by means of the fast Fourier transform, and the analysis of the fatigue index through the mean and median of the spectrum, the data are presented in Table 3. It is evident that there are significant differences in the muscle groups of the biceps, medial deltoid, latissimus dorsi, pectoralis major and trapezius.

Table 3. Fatigue analysis through spectral analysis by means of the mean and median of the Fast Fourier Transform.

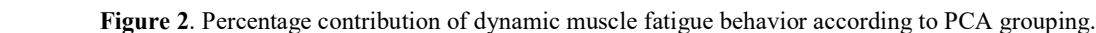
Muscular Group	Test	Mean	Std. Dev.	Coefficient of variation	Min.	Max.	p-Value	d-Cohen
Biceps	Dynamic	14,053	7,234	0,515	5,49	32,01	0,034	0,698
	Isometric	8,398	2,696	0,321	5,53	13,92		
Medial Deltoids	Dynamic	12,517	2,183	0,174	8,59	15,71	0,002	1,168
	Isometric	9,486	2,213	0,233	5,795	13,01		
Latissimus Dorsi	Dynamic	16,357	6,859	0,419	5,86	25,37	0,001	1,22
	Isometric	6,445	2,78	0,431	2,6	11		
Extensor carpi radialis	Dynamic	19,872	3,87	0,195	13,89	28,27	0,001	2,63
	Isometric	13,001	4,073	0,313	8,76	23,14		
Flexor carpi radialis	Dynamic	17,963	5,692	0,317	11,04	26,63	0,228	0,369
	Isometric	16,076	4,552	0,283	9,77	23,08		
Pectoralis major	Dynamic	14,22	5,439	0,383	6,38	27,4	0,006	0,99
	Isometric	9,252	3,18	0,344	4,69	16,25		
Upper Trapezium	Dynamic	9,955	1,953	0,196	7,32	12,47	0,007	0,957
	Isometric	8,158	3,181	0,39	3,96	12,56		
Triceps	Dynamic	19,825	5,413	0,273	12,06	28,05	0,001	1,776
	Isometric	10,878	2,99	0,275	6,18	15,5		

Correlation analysis of the study variables

The following figure shows the correlations between the study variables (figure 1).



The following figure shows the variables that contribute most to the principal component.



Clustering analysis under the factor of playing position according to the PCA

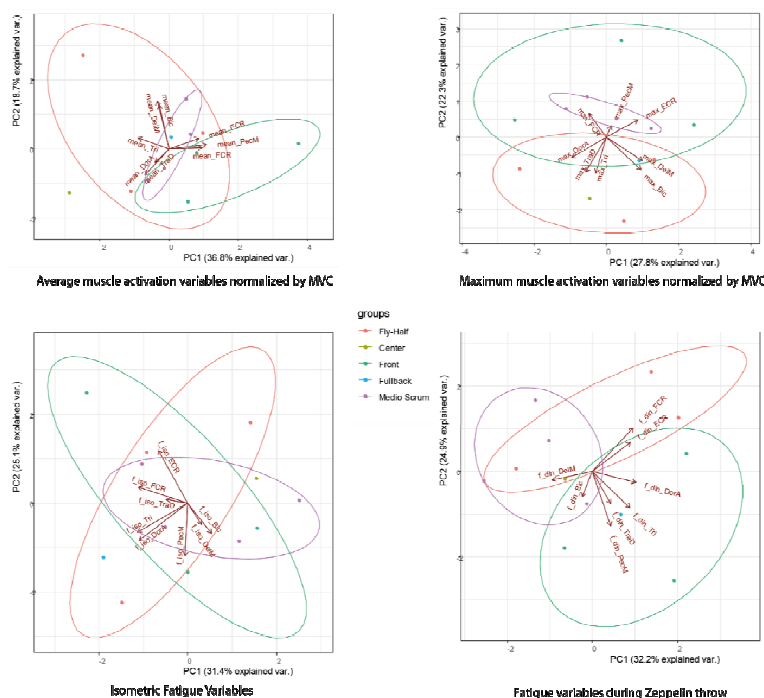


Figure 3. Identifies the groupings generated in the principal component. Grouping plot of the variables of average muscle activation, maximum muscle activation, isometric fatigue and fatigue during the Zeppelin throw according to playing position.

Discussion

The purpose of the present study was to determine the behavior of muscle fatigue during the Zeppelin passing gesture in rugby players from the city of Bogotá. The findings found are grouped into four categories that we will describe below:

Anthropometric Characteristics and Grip Strength

BMI is an indicator of the relationship between weight and height that is frequently used to identify overweight and obesity in adults. In the case of adults, WHO defines overweight equal to or greater than 25 and obesity greater than 30. According to the results obtained, it can be observed that the population evaluated is with tendencies to overweight (World Health Organization, 2022). However, according to Álvarez, due to the characteristics of the sport and the dynamics of the game, the characteristics of an elevated BMI correspond to muscle mass and increased abdominal mass (Álvarez, 2022).

In rugby, the application of strength in the grip is fundamental, as prehensile strength optimizes sport performance and minimizes the risk of injury (Cronin et al., 2017). This aspect is a physical quality described as an emerging characteristic to consider in the selection of professional athletes in the United States (Vaz, et al., 2021). The results obtained (grip strength right hand 36.8 KgF, and left hand 35.9 KgF) and according to the normality parameters reported by Cronin et al. (2017), for a population between 25 and 30 years old in this discipline, the evaluated population has a decreased strength range with respect to the values reported by the author (52.5 ± 6.47), reinforcing the importance of performing focused strength training processes, based on the fact that the flexor and extensor muscles of the fingers play a role in the grip of the ball and in the dynamics of the pass (Lewis, 2013; Cronin et al., 2017).

Muscle Behavior

During the rugby throwing gesture, it is observed that the flexor carpi radialis, triceps, biceps, pectoralis major and latissimus dorsi muscles present a percentage of activation greater than or equal to 60% with respect to the MVC. These characteristics are related to the movement gesture composed of the twisting movement generated by the thumb, the flexion and extension movement of the elbow and the stabilization component given by the pectoralis major and latissimus dorsi. Navarro in 2014 presents that during the Zeppelin throw, the ball is carried with both hands in front of the player and with a firm grip. The player's hands are separated to release the ball, and the fingers should always be well stretched to accompany the ball in its departure (Navarro, 2014). However, this author does not make a clear distinction of the most relevant musculature in this technical gesture, an aspect that we consider relevant in the present research.

When analyzing the coefficient of variation, it is observed that the triceps and latissimus dorsi muscles present a high variation among those evaluated. This represents the need to strengthen and focus training on these muscles, which, by presenting a high variation, indicate a non-homogeneity in the muscular electrical response within the mean and maximum values obtained during the throwing process with respect to the maximum voluntary contraction. Strength training allows players to adapt the neuromuscular system to increase the amount of force they can produce (Bompa & Buzzichelli, 2015), which improves the nervous response in the muscles and optimizes the contractile process at the muscular level. With maximal strength training, the speed and timing of these nerve signals improve as players progress in their strength training (World Rugby, 2020). This aspect has also been observed when analyzing the muscular behavior of the scapular area in external rotation movements, a movement very similar to rugby when the athlete performs the pass to either side (Alizadehkhayat et al., 2015).

From the correlational analyses, it is evident that during the Zeppelin throw there is a statistically significant and ideal and direct correlation between the Biceps and medial Deltoid muscles, which correspond to the functions of elbow flexion, rotation, and shoulder abduction, respectively. Likewise, with the pectoralis major, latissimus dorsi and trapezius muscles, which become agonists according to the throwing decision. Contrasting these results, studies such as Sayers (2011) show how shoulder and elbow flexion vary significantly between rugby pitchers, and there are significant differences in shoulder orientation between pitchers and pitch length. Similarly, (Rotawisky & Chiquito, 2017) posit how muscle groups are activated during the actions of the movement and in this sense, upper trunk muscle groups in the different phases of the movement which originates the erectors of the spine are activated.

Muscle Fatigue Analysis

When analyzing the muscles that presented a higher fatigue index during the dynamic test, in relation to the analysis of the average, it was observed that the extensor carpi radialis and triceps are the muscles with a greater presence of fatigue, followed by the extensor carpi radialis and flexor carpi radialis. These results relate to those presented by Tavares et al. in 2017, where the authors argue that the high density of training programs at the weekly level results in limited time for recovery, which is associated with a decrease in performance due to the presence of muscle fatigue. In addition, players are exposed to neural-type training, i.e., high load/contraction speed training, which generates results in terms of high power and explosiveness (Tavares et al., 2017). This neuromuscular aspect has been the subject of study in multiple research projects in trained population (Posthumus et al., 2020; McKinnon et al., 2017).

In team sports such as rugby, eccentric actions, such as changing direction, decelerating, braking, or propelling a ball, generate the shortening-stretching cycle and appear continuously during the development of the match. These actions cause the rupture of the cross-bridges because of the high contraction forces associated with muscle elongation, as stated by Farthing & Chilibeck (2003). Fridén & Lieber in 2001 mention that these movements cause a disruption of both contractile and other structural proteins in the muscle cell, which generates an increase in muscle fatigue (Farthing & Chilibeck, 2003; Fridén & Lieber, 2001). This situation results in the active muscle seeking another source of energy, leading to an increase in lactic acid and hydrogenions. This, in turn, generates a metabolic acidosis that can lead to muscle fiber breakdown. This situation is due to the convergence of multiple factors, the main one being the inhibition of motor function when the limit of tolerance or muscular demand is reached (CAMDE, 2021).

About fatigue analysis, significant changes were observed between the values obtained at the isometric level and the values obtained during the dynamic test (throws) in the muscles evaluated, with the exception of the flexor carpi radialis. The muscles present a large effect size, and a higher fatigue index is observed in the dynamic movements than in the isometric tests. This is because, at the muscular level, fatigue postulates the reduced capacity of muscle fibers to produce force, even in the presence of motor neuron excitation through spinal mechanisms or externally applied electrical pulses. Prior to the decrease in force, when performing physically demanding tasks, both peripheral and central alterations occur leading to changes in the activity of fatiguing muscles. These changes in the electrical properties of the muscle are referred to as the "myoelectrical manifestation of fatigue" (Marco et al., 2017). It is accepted that fatigue is related to peripheral changes at the muscle level, such as changes in neuromuscular binding and metabolite accumulation, which result in a reduced ability of muscles to generate force. This is termed "peripheral fatigue," while factors such as altered corticospinal transmission to the spinal cord, reduced excitability, and activation frequency of motor neurons, resulting in reduced drive from the central nervous system to motor neurons, are referred to as central fatigue. However, the sources of muscle fatigue and evidence of central fatigue are still debated (Contessa, 2016).

Regarding the muscles that presented a higher fatigue index during the dynamic test, studies such as the one carried out by (de Souza Castelo Oliveira & Gonçalves, 2009) have documented changes in the values of the EMG parameters, assuring that the fatigue found depended on the external load. Differences were found between muscle fatigue as a function of external load conditions, continuous static loads, and repetitive loads (Roman-Liu et al., 2004). So why is it important to review fatigue in extensor carpi radialis and triceps? Authors such as (Wang et al., 2021) found that fatigue reduces muscle force production. In addition to this, it also decreases muscle contraction, release velocity and muscle power, which causes a decrease in torque and peak force of the muscles and joints, which in turn generates a reduction in throwing velocity.

In relation to the correlational results of isometric fatigue and the flexor carpi radialis, and triceps, and triceps, and latissimus dorsi, it could be suggested, based on these findings, as stated by Elliott (2006), who states the negative effect that fatigue shows in the movements of these muscle groups in the tennis serve, that players seem to decrease the activation of these muscles, causing a decrease in speed. In turn, from the dynamic fatigue, the correlation is presented between the extensor carpi radialis and flexor carpi radialis, and between the triceps and pectoralis major. These results can be explained from the approaches of Thorsen et al. (2001), who show how fatigue can be increased during fatiguing contractions, which present a reduction in the conduction velocity and, therefore, of the characteristic frequencies of the signal.

PCA of muscular behavior in the Zeppelin throwing

Principal Component Analysis (PCA) is a widely used technique, especially in applications with high dimensionality systems (Wang et al., 2017). In the context of our study, it is applied to electromyographic recordings of different muscles during the execution of specific technical gestures in rugby. Importantly, this method is data-driven, implying that the results are intrinsically related to the data set being analyzed. In essence, PCA simplifies data sets by reducing their dimensions, which greatly facilitates their analysis (Warmenhoven et al., 2019). Because sports gestures are inherently complex, electromyographic analyses involve a wide variety of parameters and curves, which are often normalized for more accurate interpretation. From a systemic perspective, only a reduced set of variables is essential to describe muscle behavior in this context. The present study is a pioneer in using this multivariate technique in the analysis of a technical gesture in rugby, focusing on the electromyographic behavior of the muscles involved in its execution. For this reason, no research of the same characteristics is available for contrast in the literature.

From the analysis of the percentage contribution of the anthropometric variables in the grouping components, it is observed that the variables AV, LAA and AH, bilaterally, have a direct impact on the sporting gesture of the Zeppelin throw because these measures have a direct impact on the lever action and traction exerted on the ball to generate the trajectory and the throw. On the other hand, when analyzing the contribution percentages of the average muscle activation variables normalized by MVC during the Zeppelin throw, the pectoralis major, flexor carpi radialis, triceps and extensor carpi radialis muscles are the predominant ones during this activity. This correlates since, during the sporting gesture, the flexor carpi radialis and extensor carpi radialis are responsible for the wrist flexion and extension movement, the triceps acts as an elbow extensor, and the pectoralis major has functions that include arm flexion when the arm is in a position of 90 degrees or more, arm extension when the arm is in a flexion position of more than 90 degrees, and serves as a shoulder joint stabilizer.

With respect to the maximum muscle activation normalized by MVC during the Zeppelin throw, it is observed that the greatest contributions at the muscular level are presented in the medial deltoid, latissimus dorsi, biceps and extensor carpi radialis. The maximum activations are generated because the function of the medial deltoid corresponds to the development of vertical extension of the arm when the arm is in an abducted position. The latissimus dorsi acts in extension, adduction, and internal rotation of the arm and as a stabilizer of the scapula. The biceps act in elbow flexion (initial position of the Zeppelin pass), and the extensor carpi radialis acts in wrist extension and abduction.

The PCA corresponding to isometric fatigue shows that the muscles with the greatest contribution to fatigue are the triceps, flexor carpi radialis and latissimus dorsi. While during the Zeppelin throw, the percentage of dynamic fatigue contribution is represented by the latissimus dorsi, flexor carpi radialis, medial deltoid, extensor carpi radialis and triceps muscles. On the other hand, the grouping graphs of muscle activation during the Zeppelin throw, normalized by MVC by the playing position factor, show three groups for the scrum-half, opening and forward positions, which generates an independent behavior between the scrum-half and the opening position in terms of muscle fatigue behavior. It is evident that the scrum half position presents a greater muscle activation in flexor carpi radialis, pectoralis major and extensor carpi radialis, in the opening position, the greatest muscle activation is presented in latissimus dorsi, right trapezius, triceps, medial deltoid, biceps and in the forward position, muscle activation has a greater tendency in flexor carpi radialis, pectoralis major and extensor carpi radialis.

The grouping graphs of isometric muscle fatigue by playing position factor show three defined behaviors in the playing positions: the first in the opening position with predominant isometric muscle fatigue in flexor carpi radialis, extensor carpi radialis and medial deltoid, the second in the scrum half position with predominant isometric muscle fatigue in medial deltoid and biceps and the third group in the forward position with predominant muscle fatigue in latissimus dorsi, triceps, trapezius, pectoralis major and biceps.

Conclusions

The results suggest that the population evaluated tends to be overweight, but this overweight may be due to greater muscle mass and increased abdominal mass, which are relevant in the context of rugby. In addition, it was identified that prehensile strength is fundamental in this sport, and the evaluated population showed a decreased strength range compared to the average values in the discipline. This underlines the importance of specific strength training for the muscles involved in the Zeppelin grip and pass. During the Zeppelin throw, several muscles, including the flexor carpi radialis, triceps, biceps, pectoralis major and

latissimus dorsi, were observed to be significantly activated. These muscles play a key role in the execution of this technical gesture, and their activation is essential for successful performance. The extensor carpi radialis and triceps were identified as the muscles that presented the greatest fatigue during the dynamic test of the Zeppelin throw. This muscle fatigue can be attributed to the high demand of strength and energy required during this technical gesture and suggests the importance of training these muscles to improve performance and prevent injuries. The study used Principal Component Analysis (PCA) to analyze muscle behavior in the Zeppelin pass. This provides a clearer picture of the key variables that influence the execution of this technical gesture, including anthropometric characteristics and muscle activation. In addition, differences in muscle activation and fatigue were observed between different rugby playing positions.

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Conflict of interest

The authors report that there is no conflict of interest in the development of this research.

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