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Angular kinematics of the *overhead squat* and shoulder pain: a correlational analysis in CrossFit® athletes

Angular kinematics of the overhead squat and shoulder pain: a correlational analysis in crossfit® athletes

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Summary

CrossFit® is a physical training method that combines resistance, aerobic, mobility, flexibility, and muscle power exercises. Despite promoting significant gains in strength and performance, the modality is associated with a high incidence of injuries, especially in the shoulder, knee, and ankle regions. Therefore, this study aimed to analyze the correlation between the angular kinematics of the spine, hip, and ankle joints—considering the flexion and extension angles in the sagittal plane—during the *overhead squat* movement and the level of shoulder pain in CrossFit® athletes. Ten volunteers of both sexes, over the age of 18, who had been practicing CrossFit® for at least six months and who experienced shoulder pain during the exercise, participated in the study. Data collection was conducted at CrossFit® gyms in the city of Bauru, São Paulo, using specific software and a camera positioned in the sagittal plane, three meters from the participant. Filming occurred at a frequency of 100 Hz, during five repetitions of the movement. The maximum flexion and extension angles of the spine, hip, and ankle joints were analyzed. Pain intensity was measured using the Visual Analog Scale (VAS), and correlation between variables was assessed using Pearson's test, with a significance level of $p < 0.05$. The results indicated a correlation between the degree of shoulder pain and the angular kinematics of the analyzed joints, suggesting that changes in movement patterns may be related to pain in CrossFit® practitioners.

Keywords: CrossFit®; Shoulder pain; Angular kinematics; Sports injuries; Functional movement.

Abstract

CrossFit® is a physical training method that combines resistance, aerobics, mobility, flexibility, and power exercises. Although it promotes significant gains in strength and performance, the practice is also associated with a high incidence of injuries, particularly in the shoulder, knee, and ankle regions.
Therefore, this study aimed to analyze the correlation between the angular kinematics of the spine, hip, and ankle joints—considering flexion and extension angles in the sagittal plane—during the overhead squat movement and the level of shoulder pain in CrossFit® athletes. Ten volunteers of both sexes, aged over 18 years, who had been practicing CrossFit® for at least six months and reported shoulder pain during the overhead squat, participated in this study. Data collection was carried out in CrossFit® gyms in Bauru, São Paulo, using specific software and a camera positioned in the sagittal plane, three meters from the participant. The movements were recorded at a frequency of 100 Hz during five repetitions of the exercise. The maximum flexion and extension angles of the spine, hip, and ankle joints were analyzed. Pain intensity was assessed using the Visual Analog Scale (VAS), and the correlation between kinematic data and VAS scores was evaluated using Pearson's correlation test, with a significance level of $p < 0.05$. The results indicated a correlation between shoulder pain intensity and the angular kinematics of the analyzed joints, suggesting that changes in movement patterns may be related to shoulder pain in CrossFit® practitioners.

Keywords: CrossFit®; Shoulder pain; Angular kinematics; Overhead squat; Sports injuries.

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1 Introduction

The term *CrossFit®* comes from the combination of the English words *cross* (to cross, to mix) and *fit* (fitness, physical preparation), representing a functional training proposal characterized by integration of multiple physical capabilities. Developed in the United States in the 1990s, method initially gained prominence in training centers for armed forces officers, incorporating elements from various sports, such as athletics, Olympic gymnastics and weightlifting weight (Stone et al., 2006).

CrossFit® combines resistance, aerobic, flexibility, mobility *and* muscular power, performed at high intensity and short duration, generally between forty and sixty minutes per session. According to the *CrossFit Training Guide* (2012), development of the athlete in this modality is structured in a hierarchical pyramid composed of five levels: nutrition, metabolic conditioning, gymnastics, weightlifting, and sports. Each workout is divided into three phases: warm-up, technical practice and the *Workout of the Day* (Wod), which represents the main sequence of exercises prescribed for the day. With more than 17 thousand *boxes* (gyms affiliates) around the world — about 5% located in Brazil — *CrossFit®* has become a global phenomenon (Dominski et al., 2019). However, its intense practice has been associated with increased incidence of musculoskeletal injuries. Studies indicate that the most affected regions affected are the shoulder (22.6%), knee (16.5%) and lumbar (12.9%) (Montalvo et al., 2017; Wagener et al., 2020).

The multifactorial nature of *CrossFit® movements,* which involve complex gestures and of the whole body, may be directly related to the occurrence of injuries. Among the categories of *predominant* exercises are *Olympic Weightlifting,* Powerlifting and gymnastics, which include movements such as the *Snatch* and *Clean and Jerk,* aimed at developing strength, power, flexibility, coordination, and balance. Failure in any of these abilities, or the execution inadequate movement can result in joint overload and injuries (Stone et al., 2006; Glassman; Glassman, 2010). Particularly in *Powerlifting,* the Squat exercises stand out , *Dead Lift* and *Bench Press,* which prioritize maximum power production in a single effort. When performed with inadequate technique or under excessive training volume, these movements increase the risk of injuries, especially in highly mobile joints, such as the shoulder (Dominski et al., 2018).

In this context, understanding the biomechanical factors associated with pain and injuries in the *CrossFit®* is essential for developing preventive strategies and improving efficiency of movements. Kinematic analysis allows us to identify execution patterns potentially harmful and adjust the technique more precisely. Thus, this study aimed to

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objective to analyze the correlation between the angular kinematics of the spine, hip and ankle - considering the angles of flexion and extension in the sagittal plane during the movement of *overhead squat* - the level of shoulder pain in *CrossFit® athletes.*

With the increasing popularity of *CrossFit®* and the growing number of practitioners, there is a need for studies that deepen the understanding of injury mechanisms associated with the sport. Research focusing on biomechanical analysis can provide insights to identify inappropriate movement patterns and propose preventive interventions that reduce the risk of injury. In addition to contributing to the scientific field, understanding the relationship between kinematics joint and pain can favor the development of safer training strategies that preserve the performance and quality of life of practitioners. Thus, studies focused on the etiology of injuries in *CrossFit®* become essential to improve the monitoring of athletes and guidance professionals in the health and human movement fields.

This is a cross-sectional, observational study, carried out based on the analysis systematic survey of CrossFit® practitioners . Ten volunteers participated, five of each sex, aged over 18 years old, practicing the sport for at least six months and who had pain in the shoulder during the overhead squat movement . Participants were *recruited* from *CrossFit®* in the city of Bauru (SP). The inclusion criteria were: regular *CrossFit®* practice (minimum of 120 minutes per week in the last six months); presence of shoulder pain during execution of the *overhead squat;* absence of complete injuries to the shoulder tendons (rotator cuff or long head of the biceps); absence of tendon reconstructive surgeries or episodes of dislocation/subluxation in the last 12 months; and ability to perform five repetitions of the movement during data collection. All participants signed the Informed Consent Form (TCLE), in accordance with the ethical guidelines of Resolution No. 466/2012 of the National Health Council. The project was approved by the Research Ethics Committee (CEP) of the responsible institution before start of data collection.

Potential risks were minimal and limited to the possibility of skin irritations resulting from the use of photoreflective markers and mild muscle discomfort after exertion physical. None of the participants reported such adverse effects. All were advised to use topical moisturizer in case of irritation and apply ice packs for 20 to 30 minutes in case of of delayed onset muscle soreness.

As a direct benefit, participants received an individual report with information on their physical-functional capacities. Indirectly, the results of this study may contribute for the development of screening and prevention protocols for shoulder injuries during exercise squats in *CrossFit® practitioners. Confidentiality* was ensured through coding of participants one to ten, preserving their identity at all stages of the research and

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resulting publications. The data were analyzed in an aggregated form, and only averages and variations of the observed measurements. Descriptive information such as age, time of practice, height and weight were used exclusively to characterize the sample, without any possibility of individual identification. This conduct aims to guarantee anonymity, integrity and ethical use of information obtained during the study.

2 Study development

Data collection was carried out on different days, according to the availability of participants. Initially, everyone filled out a subject characterization form, containing personal and sports information, which was later tabulated and organized in a spreadsheet Microsoft Excel for descriptive analysis purposes. Data were then collected kinematics, performed with the aid of a camera positioned in the sagittal plane, at a distance of three meters from the participant. The footage of the *overhead squat* movement was captured with sampling frequency of 100 Hz, recording five complete repetitions of the exercise.

For movement analysis, photoreflective markers were positioned at points anatomical reference points on the left side of the body: axillary midline, greater trochanter of the femur and lateral condyle of the knee. Only *overhead squat* movements were considered valid performed according to the correct mechanics described in the CrossFit Training Manual (2012), that is, with the bar positioned above the head, elbows fully extended and locked and squat complete. The load adopted as protocol for the execution of the exercise corresponded to 50% of the personal record of each participant in the movement. During the execution, the maximum angles of flexion and extension of the spine, hip and ankle joints were analyzed in the sagittal plane.

The measurement of the angular amplitude was performed with the Angle Meter software, a tool that uses the tangent of gravity between two axes to measure angles or slopes. The application provides accurate results, depending on the quality of the sensors used to capture the data. According to the established protocol, each participant performed a series of five repetitions of the movement. To reduce possible biases resulting from the absence of warm-up (in the first repetition) or muscle fatigue (in the last one), only the three intermediate repetitions were considered for statistical analysis, seeking to ensure greater reliability and consistency of the data obtained.

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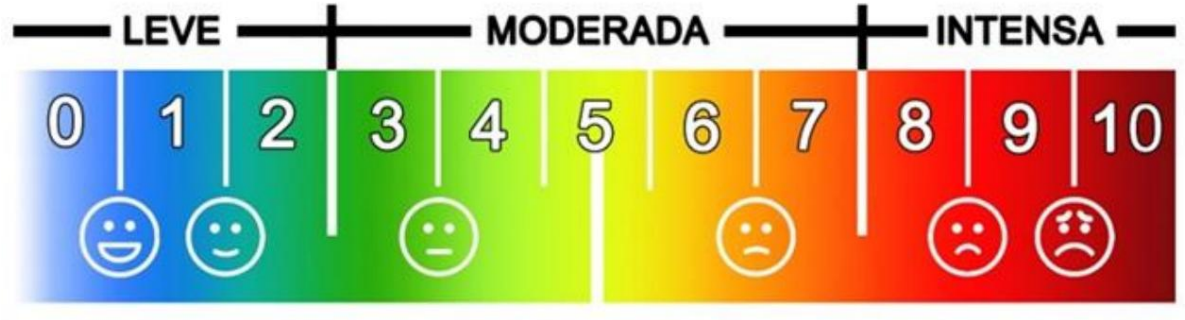
Figure 1 – Evaluation of the *overhead squat movement.*

Source: Prepared by the author

Subjective pain intensity was assessed using the Visual Analogue Scale (VAS), widely used instrument to quantify individual pain perceptions. The VAS consists in a continuous line, usually ten cm, in which the participant indicates the point that best represents the intensity of the pain felt, ranging from “absence of pain” to “unbearable pain” (Figure 2). The correlation between kinematic data and VAS scores was verified by the Pearson correlation, adopting a significance level of $p < 0.05$.

Figure 2 – Visual Analogue Scale (VAS)



Source: https://www.researchgate.net/figure/Escala-Visual-Analogica-EVA_fig1_332241604

Regarding the factors associated with shoulder pain and the time spent practicing CrossFit, results did not indicate a significant association. It was observed in the sample - composed of ten

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participants (five men and five women), most of whom practiced this sport for two to five years (60%) with a training frequency of five times a week (90%), therefore, even with high training attendance, shoulder pain was identified as a factor that occurs rarely (70%) or never (20%), as shown in Table 1.

Table 1 – Sample Characteristics

Variables	Mean and Standard Deviation
Age (years)	28 (4.76)
personal record (kg)	59.5 (18.32)
Weekly training frequency	2 to 4x/week: 1/10
	5x/week: 9/10
CrossFit practice time	0 to 6 months: 1/10
	1 to 2 years: 1/10
	2 to 5 years: 6/10
	Over 5 years: 2/10
Frequency of pain when performing the movement	Sometimes: 1/10
	Rarely: 7/10
	Never: 2/10
Pain intensity during assessment (points EVE)	0.7 (1.05)
Total Extension Angle in the Movement of *Overhead Squat*	168.93 (5.84)
Total Flexion Angle in the Movement of *Overhead Squat*	54.23 (9.77)

Source: Prepared by the authors.

Still in this table 1, it can be seen that the average age of the sample is 28 years) and the best personal record achieved in carrying out the movement, that is, the *personal record* of the observed group, obtained an average of 59.5 kg (18.32).

Regarding the associations between pain and spinal angulation during the *overhead squat movement,* there was positive correlation between the angle of the lumbar spine and shoulder pain, at the moment of full extension of the movement of *overhead squat* (p = 0.03 and r = 0.92; Table 2).

Table 2 – Correlation between pain and lumbar angle during *overhead squat movement.*

Correlations	Values of per
between lumbar spine angle and shoulder pain at the time of full shoulder extension *overhead squat* movement	0.03 and 0.92*
Lumbar spine angle and shoulder pain at the moment of full flexion of the *overhead squat* movement	0.73 and 0.35

* significant difference, p < 0.05.

Source: Prepared by the authors

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In this sense, based on the general objective of this study - which was to analyze the existence correlation between the angular kinematics of the trunk (angle of flexion and extension, in the sagittal plane) during the *overhead squat* movement and the level of shoulder pain in CrossFit athletes -, verified- It is known that the smaller the angle of the lumbar spine of the CrossFit practitioner at the moment of full extension of the overhead squat movement , the greater the pain the athlete feels in the shoulder ($p = 0.03$ and $r = 0.92$), in Table 2.

According to The CrossFit Training Guide Level 1 (2007), the *overhead squat* is a overhead barbell squat, which has a similar starting position to the *air squat* (free squat with only body weight). However, in this exercise you hold the bar with hands wide apart, shoulders push the bar upwards and armpits should be facing forward. Its execution is also similar to the *air squat* - in which the person stands, without any weight external, squat until the hip passes the knee line, breaking the parallel, and stand up again. However, with the difference that the athlete squats keeping the overload above the head and the bar must move in line with the middle of the feet, with the elbows fully extended.

Therefore, during the movement, the athlete who throws the bar back decreases the angle of the spine. lumbar, due to the change in the center of gravity of the shoulder resistance that is thrown subsequently, generating a lumbar hyperlordosis, projecting the trunk forward to seek balance (Brukner et al., 2001), causing the lever mechanism in the shoulder joint placing it in the most unstable position, which is when there is a combination of abduction and rotation external of the shoulder joint (Kapandji, 2018).

This position has been linked to shoulder pain in athletes in two studies, such as:1) when Tirman et al. (1994) explain that abduction and external rotation evidence posterolateral impact superior glenoid and increases the anterior translation of the humeral head, relating the position with painful shoulder of *overhead* athletes .; and 2) when Clarsen et al. (2014) bring an analysis, in which identify external shoulder rotation as a risk factor for pain in this joint. This mechanism pushes the head of the humerus, pulling on the structures in the region (joint capsule, labrum, rotator cuff tendons and long head of the biceps), increasing the chances of injuries to these and may incite changes associated with the reduction of the subacromial space (Kapandji, 2018).

Thus, according to the research by Teixeira et al (2020) which deals with the main causes of injuries self-reported by CrossFit athletes, poor technique was the most prevalent factor between them. In addition to this, it was observed that practitioners who maintain the shoulder and trunk according to the correct *overhead squat* technique, they do not report shoulder pain during the movement.

It is also important to report non-observance of association in relation to sex since in the sample 50% of women and 50% of men were analyzed, and in both variables the shoulder pain was reported as rare (70%) or non-existent (20%). Only one participant reported

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feel pain sometimes. Among the 80% who reported some frequency in this item, the index of pain level was 0.7 on the VAS scale.

However, it is understood that further studies involving the protocol are still needed. shoulder exercises and with more consistent samples, since with a small sample size (only ten athletes) makes it difficult to assess the significant differences in frequency distribution between the categories. This is because a small sample may not provide enough information on the population and therefore not be able to detect real differences between the observed variables. Low sample representation can also result in less accurate data in the analysis. statistics. However, despite limitations with the analysis of only ten people in the study, it was a fair representation, as several different boxing athletes in the city of Bauru, from various CrossFit categories. There was also a relevant connection based not only on the empirical research, but in previous works and studies and in the literary review, which helped in understanding of the subject, especially because the challenge was to find participants with the desired profile and availability for testing. Limited access to these respondents; practical difficulties and time available to explore the research question and monitor changes as they occurred were the main limitations. And, due to the importance of this subject and the lack of studies in the area specific *overhead squat* indicates the need for future research with a larger framework theoretical and investigative to support the hypotheses raised here.

3 Considerations

This research showed that there is a correlation between the angle of the lumbar spine and pain in the shoulder, since at the moment of full extension of the *overhead squat movement,* the smaller the the angle of the lumbar spine, the greater the pain will be during this Crossfit® movement.

As stated in the relevant literature, among the most injured joints in the sport CrossFit sports, the shoulder region is the most reported, which can lead to symptoms of pain and, therefore, consequently, setbacks in the quality of life of those who practice this exercise.

In the empirical investigation, a method was used to measure the intensity and interference of pain, subject characterization form and kinematic data collected with a camera, positioned in the sagittal plane for filming the *overhead squat* movement at a sampling frequency of 100 Hz during five repetitions of the exercise. *Overhead* movements were considered valid *squat* in which the participant performed squats, with the bar above the head and with elbows, fully extended and locked.

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