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Two-dimensional video analysis of the overhead squat: a preliminary study
Análisis de vídeo bidimensional de sentadilla sobre la cabeza: un estudio preliminar

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Abstract. The aim of this study was to identify changes in the pattern of movement during performance of the overhead squat, as well as possible differences between the sexes, during a protocol of an extreme conditioning program. The subjects were eleven men (28.6 ± 4.5 years, 85.1 ± 8.4 kg, 1.80 ± 0.07 m, and 13.8 ± 7.7 months of practice) and eleven women (30.5 ± 4.8 years, 68.2 ± 10.36 kg, 1.70 ± 0.05 m, and 20.3 ± 17.01 months of practice), all of whom were extreme conditioning program practitioners. The protocol chosen for the training was the "Nautical Nancy", which consisted of 5 rounds of 15 overhead squats and 400 meters of rowing. During the exercise, an analysis was performed in which the shoulder, knee, and hip flexion angles were analyzed in the first and last rounds. For men, there were increases of the shoulder and hip flexion angles, while the women showed increase of the shoulder flexion angle and decrease of the knee flexion angle. Changes in technique occurred due to the attempt at self-preservation on the part of the practitioners, when exposed to the protocol, which could lead to increased risk of injury.
Key words: CrossFit; High Intensity Functional Training; Resistance Training; Biomechanics; Exercise Technique.

Resumen. El objetivo de este estudio fue identificar los cambios en el patrón de movimiento durante la ejecución de la sentadilla por sobre la cabeza, así como las posibles diferencias entre los sexos, durante un protocolo de un programa de acondicionamiento extremo. Los sujetos fueron once hombres (28,6 ± 4,5 años, 85,1 ± 8,4 kg, 1,80 ± 0,07 m y 13,8 ± 7,7 meses de práctica) y once mujeres (30,5 ± 4,8 años, 68,2 ± 10,36 kg, 1,70 ± 0,05 m y 20,3 ± 17,01), todos practicantes del programa de acondicionamiento extremo. El protocolo elegido para el entrenamiento fue el "Nautical Nancy", que consistió en 5 rondas de 15 sentadillas sobre la cabeza y 400 metros de remo. Durante el ejercicio se realiza un análisis en el que se analizaron los ángulos de flexión de hombre, rodilla y cadera en la primera y última ronda. Para los hombres, hubo aumentos en los ángulos de flexión del hombre y la cadera, mientras que las mujeres mostraron un aumento del ángulo de flexión del hombro y una disminución del ángulo de flexión de la rodilla. Los cambios en la técnica ocurrieron debido al intento de autopreservación por parte de los practicantes, cuando se expusieron al protocolo, lo que podría conducir a un mayor riesgo de lesión.
Palabras claves: Crossfit; Entrenamiento Interválico de Alta Intensidad; Entrenamiento de Fuerza; Biomecánica; Técnica de Ejercicio.

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Introduction

Extreme conditioning programs (ECPs) have gained in popularity in recent years (Aune & Powers, 2017; Tibana & de Sousa, 2018). These forms of training use high volume and high intensity repetitions, with short or no rest periods (Hooper et al., 2014; Lichtenstein & Jensen, 2016). In addition to constantly varied movement with moderate to high loads, including metabolic exercises, gymnastic movements, and Olympic weightlifting (OW) (Hooper et al., 2014; Lichtenstein & Jensen, 2016). The protocols adopted involve the coordination of large muscle groups and multiple joints, using basic OW exercises such as squats, deadlifts, snatch, and clean and jerk, among others (Hooper et al., 2014). The inclusion of these OW movements has become an area of emphasis in such training programs (Hedrick & Wada, 2008).

The OW movements are consistently those most cited as possible causes of injuries in ECP practitioners, with greater incidence in the shoulder, lumbar, and knee regions (Keogh & Winwood, 2017). Male practitioners tend to injure themselves more frequently than females, despite the fact that the biomechanical patterns of women result in more musculoskeletal stresses that increase the risk of injury (Mauntel et al., 2015; Weisenthal et al., 2014).

Injury rates are higher in ECP than in OW practitioners, due to the fact that the exhausting routines of ECPs lead to faster muscle fatigue, which when associated with complex movements can increase the degree of risk (Hak et al., 2013). Errors in technique, together with muscle fatigue, are identified as the main risk factors for these injuries (Keogh & Winwood, 2017).

Examples of complex ECP movements are snatch and clean and jerk, performed with high intensity muscle contractions, requiring high levels of strength and momentum (Hak et al., 2013). The overhead squat (OHS) is one of the exercises most used during learning of these movements, due to their similarity with the bar grip phase (Altepeter & Mike, 2017; Soriano et al., 2019).

The OHS, a functional movement used to improve performance, emphasizes the strength of the posterior chain and the stabilization required to keep the bar above the head (Altepeter & Mike, 2017). It allows the practitioner to feel comfortable, since the movement necessitates a neuromuscular balance similar to that in the snatch (Altepeter & Mike, 2017; Aspe & Swinton, 2014).

This exercise is difficult to execute and is used in evaluation of functional movement (Clifton et al., 2015). Given the indications of high injury rates and the considerable demand for sports that involve these movements, it is important to have accurate knowledge of the effects on the joints involved in each phase of the OHS, in order to be able to improve training, enhance performance, and predict injuries (Sprey et al., 2016).

Therefore, the aims of this study were to identify changes in the pattern of movement while performing the OHS (assessed by sagittal 2D kinematic analysis), together with possible differences between the sexes, during a predefined protocol for ECPs.

Materials and Methods

Subjects

All the subjects evaluated in the study were CrossFit® practitioners familiar with the OHS. The risks and benefits of the experiment were explained to all the participants, who subsequently signed a free and informed consent document approved by the Ethics Committee for use in humans.

For the inclusion of the subjects in the study, it was necessary to practice in an affiliated CrossFit gym, not to have any musculoskeletal discomfort that would hinder the evaluation, and to have had at least six months of practice. Injury rates can be significantly higher in athletes with little training time, requiring care to ensure the correct movement patterns in these practitioners (Mehrab et al., 2017).

Twenty-two practitioners were evaluated in the study, consisting of 11 men (28.6 ± 4.5 years; 85.1 ± 8.4 kg; 1.80 ± 0.07 m; body mass index 27 ± 1.67; and practice for 13.8 ± 7.7 months, 4.4 ± 1.12 days per week) and 11 women (30.5 ± 4.8 years; 68.2 ± 10.36 kg; 1.70 ± 0.05 m; body mass index 24.5 ± 2.80; and practice for 20.3 ± 17.01 months, 5.2 ± 0.87 days per week).

Evaluation Protocol

Before performing the evaluation protocol, the Perceived Recovery Status Scale was applied. In sports, this scale is used as a tool to identify the first overtraining indicators, in addition to allowing individuals to adjust training loads and volumes. The scale was applied prior to the session and if the participant reported a value less than five on the scale, the session was suspended and scheduled again for the same week and at the same time (Mehrab et al., 2017). All the evaluations were carried out at the same time of the day, between 10:00 a.m. and 3:00 p.m., in the same week.

Before the protocol, the subjects performed a warm-up, which consisted of five minutes on a cycle ergometer at resistance level five, with a speed of 60 rpm. This was followed by dynamic stretches, including body weight squats, forward and lateral lunges, knee hugs, quadriceps stretches, and a straight leg march (Hooper et al., 2014). The training took place in a temperature-controlled environment 22-25°C, with monitoring by a properly trained professional.

The chosen protocol was the "workout of the day" (WOD), "Nautical Nancy®", which consisted of 5 rounds of 15 overhead squats and 400 meters of rowing, performing the protocol in the shortest time possible. All the subjects completed the WOD individually. The training loads were predefined by the protocol and consisted of 43 kg (95 pounds) for men and 29 kg (65 pounds) for women.

Before the WOD, markers with contrasting colors, easily recognizable by the software, were placed on the dominant side of each subject, on the side of the bar, on the lateral malleolus, on the side to the knee joint center, on the side to the anterosuperior iliac spine, laterally to the nipple line (men), and laterally to the height of the xiphoid process (women). These markers enabled measurement of the knee flexion angle, hip flexion angle, and shoulder flexion angle (Figure 1).

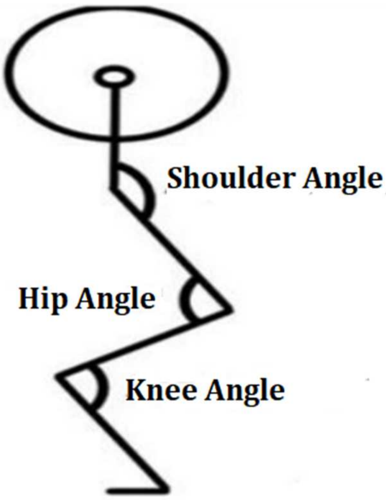

Figure 1. Shoulder, hip, and knee angles measured during the overhead squat.

The squats were filmed with a video recorder and were later analyzed using Kinovea® 0.8.27 video analysis software, for a two-dimensional kinematic evaluation of the OHS. The knee, hip, and shoulder flexion measurements were recorded at the top and bottom of each squat repetition, with the bottom being considered as the last frame before the subject performed the upward movement. The camera was positioned on a tripod, at a height of 1.5 m and distance of 2.5 m from the participant.

The subjects were instructed to perform all the prescribed repetitions as rapidly as possible and without pausing. Markings were made on the floor, so that all the repetitions were performed in the same position, and the time to complete the WOD was recorded. The round time was also recorded, with the point of reference for the start of a new round being the moment when the subject adopted the overhead position.

Immediately after completing the protocol, all the subjects provided subjective perceived exertion responses, using the Borg CR10 scale, which is a useful tool for prescribing and controlling training intensity during sessions of an extreme conditioning program, due to its high correlation with lactate and the number of repetitions completed (Alsamir Tibana et al., 2019; Foster et al., 2001; Morishita et al., 2018).

Training Load Quantification

For quantification of the magnitude of the internal load, by means of the subjective perceived exertion (SPE) for the session, the product of the SPE score was multiplied by the duration of the session (in minutes). The resulting value reflected the magnitude of the daily internal load of the training session (in arbitrary units). Other studies have used the session SPE method to quantify the internal load of training in various sports (de Andrade Nogueira et al., 2016; Freitas et al., 2014).

Data Analysis

The mean values for the shoulder, hip, and knee flexion angles in men and women were calculated for each repetition. The difference between the highest and lowest values for each angle was taken as an index of change in the technique. The coefficient of variation between the first and last rounds was evaluated for the three joints. Only the first and last rounds were analyzed, and the angular values for the three joints were compared. The variations between the rounds and the times for completion of these rounds were evaluated using the dependent t-test, while the independent t-test was applied for the differences between men and women.

Person's test was used for the correlation between the mean angular values for the three joints and the angular variations of the first and last rounds, the time of practice in the modality, the Borg CR10 scale, the time for completion of the WOD, and the Perceived Recovery Status Scale result. Correlations values will be classified as very low between 0-0.01; low with 0.1-0.3 values; moderate between 0.3-0.5; high between 0.5-0.7; very high between 0.7-0.9; and between 0.9-1.0 almost perfect (Hopkins et al., 2009). All the statistical tests were performed using SPSS software (SPSS Inc., Chicago, IL, USA). An *a priori* alpha level of 0.05 was adopted in all the analyses.

Results

The results provide the average values for the Perceived Recovery Status Scale, the time for completion of the WOD, the times for completion of the first and fifth rounds, the Borg CR10 scale, the internal load of the session, and comparison between the two groups for all the variables (Table 1).

Table 1.
Data on sports practice among the subjects.

Mean (SD)	Men	Women	*p*
Practice time (months)	13.8 (7.77)	20.3 (17.01)	0.272
Weekly frequency (days)	4.4 (1.12)	5.2 (0.87)	0.071
Perceived Recovery Status Scale	8.9 (1.58)	7.9 (1.45)	0.137
WOD completion time (minutes)	19.49 (5.15)	19.56 (4.96)	0.973
Round 1 completion time (minutes)	3.31 (0.71)	4.01 (1.21)	0.116
Round 5 completion time (minutes)	3.93 (1.50)	3.48 (0.93)	0.414
Borg CR10 scale	7 (1.79)	8.5 (1.21)	0.039*
Training load quantification (AU)	140.97 (60.89)	167.66 (57.19)	0.302

WOD = Workout of the day; SD = Standard deviation; *p<0.05.

For women, the mean angular values for shoulder, hip, and knee flexion during the WOD were 207.7° ± 1.11°, 95.2° ± 0.99°, and 93.96° ± 1.52°, respectively. For men, the mean values were 204° ± 2.12°, 101.9° ± 4.7°, and 108° ± 4.67°, respectively. The mean angular values for the three joints in the first and last rounds, the completion times, and the angle variation quotient values are compared between groups and within the same group (Tables 2 and 3).

Table 2.
Comparison between the mean values of the hip, knee, and shoulder flexion angles for the first and last rounds.

Mean (SD)	First round	Last round	*p*
Men			
Completion time (minutes)	3.31 (0.71)	3.93 (1.50)	0.194
Shoulder flexion (degrees)	200.98° (2.2)	203.84° (2.1)	0.004*
Hip flexion (degrees)	94.15° (2.07)	102.55° (3.2)	0.000*
Knee flexion (degrees)	116.78° (31.8)	105.65° (1.9)	0.190
Women			
Completion time (minutes)	4.01 (1.21)	3.48 (0.95)	0.036*
Shoulder flexion (degrees)	205.95° (1.6)	208.8° (1.3)	0.000*
Hip flexion (degrees)	94.85° (1.8)	94.96° (1.8)	0.796
Knee flexion (degrees)	95.85° (0.9)	91.87° (0.9)	0.000*

SD = Standard deviation; *p<0.05.

Table 3.
Comparison between the mean values of the hip, knee, and shoulder flexion angles for men and women.

Mean (SD)	Men	Women	p
First round			
Shoulder flexion (degrees)	200.98 (2.2)	205.95 (1.6)	0.000*
Hip flexion (degrees)	94.15 (2.07)	94.85 (1.8)	0.338
Knee flexion (degrees)	116.79 (31.8)	95.85 (0.9)	0.000*
Last round			
Shoulder flexion (degrees)	203.84 (0.43)	208.8 (1.3)	0.000*
Hip flexion (degrees)	102.55 (3.2)	94.96 (1.8)	0.000*
Knee flexion (degrees)	105.65 (1.9)	91.87 (0.9)	0.000*

SD = Standard deviation; *p<0.05.

For men, positive and strong correlations were found between the hip and shoulder flexion values in the first round (r = 0.781, p = 0.001), and between the shoulder flexion values in the last round and the knee and hip flexion values in the last round (r = 753, p = 0.001, and r = 0.746, p = 0.001, respectively). Positive and moderate correlation was obtained between the knee and hip flexion values in the last round (r = 0.637, p = 0.011).

For women, a strong negative correlation was found between the result of the Perceived Recovery Status Scale and the time of practice (r = -0.873; p = 0.000). A strong negative correlation was also found between the time of practice and the time for conclusion of the WOD (r = -0.738, p = 0.026). Strong positive correlation was observed between the weekly frequency and the Perceived Recovery Status Scale result (r = -0.715, p = 0.013).

Discussion

The aims of this study were to identify changes in the movement pattern during OHS performance, as well as differences between genders, during a predefined protocol for ECPs. A novelty of the work is the analysis of the OHS by means of two-dimensional kinematics, underscoring the need for more studies on the theme.

Between the first and last rounds, the men showed increases of the shoulder and hip flexion angles, while the women showed increase of the shoulder flexion angle and decrease of the knee flexion angle.

In a good OHS, for balance and stability, the bar should always remain aligned with the middle of the foot. The correct technique is critical, because if at some point the practitioner becomes unstable, pushing the bar forward or backward can lead to injuries (Horschig et al., 2017).

Altering the position of the bar appears to be common, since in another study, only a small percentage of healthy individuals successfully completed the movement (Teyhen et al., 2012), with the subjects tending to push the bar backwards during the procedure, as shown by the average shoulder flexion value of 200° found for both groups.

The shoulder is the location for which there are the most self-reported injuries, with practitioners citing inappropriate technique as one of the main factors, associated with frequent exposure to hyperflexion and abduction (Aune & Powers, 2017; Dominski et al., 2022; Hak et al., 2013). The mean shoulder flexion values found for both groups were suggestive of hyperflexion, putting the shoulders of these subjects at possible risk during performance of the OHS. In this position, there is ligament laxity, while muscle insufficiency could also affect the ability to maintain joint stability.

It has been reported that the ideal shoulder flexion angle is 180° and that coaches should instruct practitioners to keep their arms above the head at all times, so that the arms represent a continuation of spinal alignment (Bishop et al., 2016). The flexibility levels of shoulder movements performed by women practicing ECPs (Magalhães et al., 2020) showed a tendency to decrease with longer time of practice in the modality, indicating the need for attention of the practitioner, together with adequate training, in order to avoid the development of inappropriate movement patterns.

The OHS is one of the exercises most likely to be involved in possible injury, due to the significant load placed on the shoulders, so it is essential that coaches are aware of the skills of the practitioners (Aune & Powers, 2017). The inclusion of the OHS for screening movement patterns is important because of its ability to test and challenge the joint mobility of practitioners, involving a greater amount of muscle than other variations such as the back squat, for example. The analysis of movement patterns without the arms above the head can result in a lack of information on aspects such as trunk stability and shoulder position (Aspe & Swinton, 2014; Bishop et al., 2015).

In comparison to the genders, the men presented a higher value for the knee flexion angle in the first round, as well as higher values for the hip and knee flexion angles in the last round. The women presented higher values for the shoulder flexion angle in the first and last rounds during the performance of the OHS.

In two other studies that analyzed changes of the hip and knee angles in execution of the back squat and the bodyweight squat, during the same ECP WOD, decrease of the knee flexion angle and increase of the hip flexion angle were observed for both men (in the bodyweight squat) and women (in the back squat) (Frost et al., 2015; Hooper et al., 2013).The two studies had methodological differences, compared to the present work, since maximum repetitions were used throughout the WOD.

In the last round, the men showed increased hip flexion angle, compared to the first round, while the women showed decreased knee flexion angle. These changes in technique, as in the studies cited above, were probably a demonstration of self-preservation, with the squat being abbreviated when the individuals were submitted to programs with a high number of repetitions. This suggested that they were unable to use the same proprioceptive mechanisms, altering the efficiency of movement and potentially increasing the risk of injury by various mechanisms (Hooper et al., 2014). Changes in technique and muscle fatigue are highlighted as the main risk factors for such injuries in these practitioners (Hooper et al., 2013).

The men showed an increase in hip flexion during the last round and had significantly higher hip flexion values, compared to the women, as observed in another study with analysis of the OHS for only five repetitions, where men also presented greater hip flexion than women (Mauntel et al., 2015).

Individuals with greater hip flexion have increased forward inclination of the trunk, which can be associated with higher shear force in the spine, potentially leading to compensation and injuries in the lumbar region. Consequently, this region was at risk of injuries in the men participating in the study, during the performance of the OHS (Hooper et al., 2014).

These compensations, such as leaning the trunk forward and increasing the hip flexion angle, do not seem to happen in small ranges of motion, so it is important for the trainer to observe the capacity of each participant, so that the execution remains correct throughout the entire range of motion (Bishop et al., 2016).

In a study that evaluated the influence of movement speed during various tasks in male firefighters, it was found that when performing a squat, practitioners tended to decrease the knee flexion angle and increase the hip flexion angle (increasing the trunk flexion angle) (Frost et al., 2015). This change in the pattern of movement was attributed to the fact that the subjects were instructed to perform the movement as quickly as possible, resulting in their attention shifting from posture and movement (internal focus) to the speed at which the movement was performed (external focus), which could cause them to ignore movement patterns that would allow them to move more effectively or safely (Frost et al., 2015).

A similar effect could have occurred in the present work, because the practitioners were instructed to perform the repetitions as quickly as possible, and a characteristic of the WOD was that in a competition, the practitioner with the fastest movement would be the winner, rather than the one with the most effective movement.

Another study evaluating the influence of load on the pattern of joint movement showed that the subjects also used the hip-to-knee strategy, with hip dominance increasing as the load increased, suggesting that varying load could lead to continuous change in the mechanics of the movement (Flanagan & Salem, 2008). This could have occurred here, although it was not possible to fully understand the perception of each subject concerning the load imposed by the WOD.

For the men in this study, strong and positive correlations were found between hip and shoulder flexion, between knee and shoulder flexion, and between hip and knee flexion, showing the importance of a global analysis of the joints and their influence on the execution of the movement. For example, low hip stability can lead to greater recruitment of the rectus femoris, due to compensation, which can put the knee joint at risk (de Souza et al., 2017).

Hence, for the practice of ECPs, care is recommended so that it can minimize the exposure of the practitioners to injuries. This should include evaluation of the movements of the practitioners, correct progression during training, correct rest intervals between training sessions, direct supervision by the trainers, and the awareness of the practitioner.

Changes or errors in technique, together with muscle fatigue, are identified as the main risk factors for injuries in these practitioners (Keogh & Winwood, 2017). Maté-Muñoz et al. (2017) analyzed the levels of lower limb fatigue in different WODs, observing that the WOD with more Olympic weightlifting movements was associated with high lactate levels, making the practitioners more susceptible to fatigue.

Fatigue may be caused by high intensity and volume during ECP sessions, added to short rest intervals. Consequently, in addition to the high technical demand of exercises such as the OHS, these fatigue processes, when not mitigated, can cause injuries due to failure to perform the movements (Smilios et al., 2010).

The intensity of the exercise sessions can be monitored by the subjective perception of exertion and its correlation with lactate and the number of repetitions performed, providing a practical and economical tool for the prescription and monitoring of training (Alsamir Tibana et al., 2019). In this study, the practitioners presented subjective perception of effort values of 7 ± 1.79 for women and 8.5 ± 1.21 for men, which, despite being high to very high values, were not correlated with angular changes during the WOD.

A possible limitation of the study was the difficulty in standardizing the intensity of the load based on a predefined protocol of the modality, since practitioners may present differences in their perceptions of the intensity of the WOD. Nonetheless, an attempt was made to estimate the day-to-day maxima for the modality. The low number of participants could also be considered a limitation.

However, it was possible to obtain a preliminary elucidation of the posture patterns associated with the execution of movements for this sport modality. This was achieved using methods that are inexpensive and easy to apply, including the Perceived Recovery Status Scale (Laurent et al., 2011), the Borg CR10 scale (Foster et al., 2001; Morishita et al., 2018), and 2D analysis. Two-dimensional analysis is a reliable and valid tool that allows professionals from different areas of health to identify changes and risks in movements, enabling adjustments and timely interventions (Ribeiro et al., 2020; Schurr et al., 2017). Despite the control with tools that are easy to apply, the study sample is a limitation of the study, as its number is limited and was chosen for convenience, and thus may not represent the real result of changes. Therefore, more robust studies are needed.

The practitioners showed changes in the pattern of movement during the protocol, with alteration of their squat technique. Such changes in technique due to exposure to an excessive number of repetitions can increase the risk of injury. The participants abbreviated the movement in an attempt at self-preservation, but changes such as shoulder hyperflexion and increased hip flexion could occur as a result of exposure to moderate to heavy loads, with little or no rest interval. The men made greater use of the hip strategy, while the women had higher mean hyperflexion values. Both of these changes should be noted by coaches and practitioners, in order to minimize the risk of injury.

Practical Applications

The results found point to the need to know the different postural patterns related to the individual's biotype, the training time and the load used. This knowledge becomes an important resource for professional trainers. For extreme conditioning program practitioners, the perception of their posture is important for knowing their limits and, thus, avoiding injuries and loss of sports performance. The results also indicate that new studies are directed to analyze with different loads, different age groups and training time, in addition to evaluation in other positions and exercises used in this program.

Conclusions

It is concluded that there are changes in relation to genders. Men use the hip strategy more and women have higher mean values of hyperflexion. Changes such as hyperflexion of the shoulder and greater flexion of the hip occur when exercisers are exposed to a moderate to heavy load, with little or no rest interval.

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Conflicts of interest

All authors declare no potential conflict of interest related to this article.

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