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Biomechanical Evaluation of the Push-Up Exercise of the Upper Extremities from Various Starting Points

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Abstract:

The purpose of the present research was to evaluate the push-up exercise of the upper extremities in respect of biomechanics, to compare the muscle function, while changing the position of performance and to examine the torso's inclination during the exercise. The result is that the activation of the muscles, apart from the triceps brachii muscle, does not differentiate significantly in any of the positions. Moreover, the elevating the hands above the feet position is not recommended in protocols where the aim is to improve the muscle force because it displays the lowest mean value of vertical force and a low RFD. On the other hand, the standard push-up position is considered to be the most appropriate when the aim is to improve the triceps brachii muscle's force because it displays the highest RFD and the highest activation of this muscle. Finally, the correct body position during this exercise prevents from incorrect and damaging inclinations of the torso.

Key words: Biomechanical Evaluation , Electromyography , Push-Up Exercise.

Introduction

The push-up exercise is widely used for the training of the torso (Freeman et al. 2006), the muscles of the upper extremities (Donkers et al. 1993), the serratus anterior muscle and the stabilizing muscles of the scapula (McCann et al. 1993, Decker et al. 1999). It is also used in the rehabilitation and recovery protocols mostly after injuries or surgical procedures on the glenohumeral joint (Kibler, 1998; Decker et al. 1999; Ekstrom et al. 2003; Molongie et al. 2007), during military training (Bell et al. 2000; Knapik et al. 2001; White et al. 2007) and in various protocols which study the general physical ability (Gregg et al. 2002, Lin et al. 2006). Moreover, Kotani and Tokuhiko (2002) mention the great importance that push-ups have on Activities of Daily Living (ADL) for people with Spinal Cord Injury (SCI).

Although this particular exercise is very popular and it is used as a kind of movement even in daily activities, there are very few kinesiological studies (Anderson et al. 1984). Donkers et al. (1993) specifically mention that even if push-ups is the most popular exercise which is used to strengthen the muscles and the upper extremities, there is very little data on kinematics and kinetics regarding this activity due to the difficulties in measurements.

The fact that the specific exercise is a widely spread exercise is due to the significance of the muscular group that exerts, just like the anterior cogged muscle and the muscles that standardize the scapula (Decker 1999).

Freeman et al. (2006) mention that the standard push-up position is the one where the palms and the toes touch the ground. The anatomical curves of the spine are maintained and there is an upright body position from the glenohumeral joint to the knee joint. The hands are straight and the glenohumeral joint is right above the wrist joint. From this position the body lowers down towards the ground with a 90° flexion of the elbows, the hands are extended and it comes back to its initial position. The concentric phase of the movement is slow and the eccentric phase is explosive. To be more specific regarding the hand position, the middle finger must be under the acromio-clavicular joint (Lehman et al. 2007). Moreover, regarding the concentric phase, many researchers support that the chest should reach the ground as much as it can before the eccentric phase begins (Donkers et al. 1993). This position is the basis for all variations of the push-up exercise (Freeman et al. 2006), such as the one where the hands are placed either wider apart from the shoulders, usually at a distance 50% greater than the width between the shoulders or they are placed closer, reducing the distance from the shoulders' width at less than 50% (Donkers et al. 1993). Also, there could be a change in the height of the support base, so

the upper extremities would be in a support base higher than the position of the lower extremities (positive inclination) or the lower extremities are placed higher (negative inclination), (Ludewig et al. 2004; Lehman et al. 2006; Lehman et al. 2007). There are also changes concerning the type of the support surface which can be a steady level, such as the ground or a bench or an unsteady level, such as a balance board, a Swiss ball or even a simple ball (Donkers et al. 1993; Ludewig et al. 2004; Freeman et al. 2006; Lehman et al. 2006; Lehman et al. 2007). Finally, there are other variations of this exercise some of which are easier regarding their performance and aggravation, such as the bended knees and hips position and the upright position with the upper extremities touching the wall (Hartmann & Tünnemann 1991; Lear & Gross 1998; Decker et al. 1999; Lehman et al. 2007). Decker et al. (1999) mention that performing the push-up exercise based on the knees instead of the toes is a friendlier position for the glenohumeral joint having almost the same electromyographic activity in most muscle groups. This variation is preferred mostly by people who cannot manage the standard push-up exercise due to limited strength (Hartmann & Tünnemann 1991).

The anterior cogged muscle, which is often described as the main motor muscle of the scapula is one of the major muscles that take part in the push ups. It is also the only muscle among the shoulder pectoral muscles that takes part in all the motions (in all three dimensions) of the scapula during the rising of the upper limb (Ludewig et al. 2004). The fatigue or the weakness of the anterior cogged muscle decreases the course of the rotation of the scapula, allowing thus its peak to move forward and upward, leading to possible injury. For the above reasons, the strengthening of the anterior cogged muscle is critically necessary (Decker et al. 1999). One of the main muscles that act during the push ups, is the major pectoral muscle. Lehman et al. (2007) found that its activation is not affected by the stability of the surface support (e.g. ball or ground), as it doesn't work with the purpose of stabilizing the shoulder joint or that of the elbow. Drake et al. (2006) have come to the above conclusion, investigating the possible advantages of the ball (unstable ground), in comparison with the gymnastics mat (stable ground). Moreover the function of the trapezius has been studied during the push ups from various starting points, leading to the conclusion that its activation is low for all the phases, excluding the eccentric, not only in people with malfunctions or shoulder injuries, but also in healthy people (Ludewig et al. 2004). As far as the deltoid is concerned, Decker et al. (1999) found that the push ups plus, among other shoulder rehabilitation exercises, caused the greatest average (103% MVC) and the greatest activation peak (185% MVC) of the anterior part of the deltoid, during the maximum force application phase. Similarly, de Oliveira et al. (2007) found an increase in the activation of the anterior part of the deltoid, during the exercises that were exerted on a ball, in comparison with a stable support surface.

Finally, in relation to the abdominal and dorsal muscles, in an investigation which compares an unstable surface with a stable one, it is referred that it is not possible to draw the conclusion that an unstable surface automatically causes an increase of the muscular activity. Moreover, an unstable surface is enough to be inadequate to affect all the muscular groups. It was proven that the unstable surface should be placed under the upper limbs to cause a supposed unsteadiness (balance disorder) and therefore, an ensuing increase of the muscular activity during the push ups. It is also clearly seen that as it grows upwards, the distance of the mass center from the support base, the muscular activity can be affected. In general, for the unstable support surfaces, in comparison with the stable ones, it can't be clear if any alteration in the muscular activity is not simply the effort of the person to balance, as not all the participants responded in the same way, in the change of the stability of the support surface (Lehman et al. 2006). Also, clinical investigations show that the performance of the push ups causes pain in the waist to some people, whilst others are relieved. Therefore, the understanding of the performance mechanisms of the push ups leads to a better prevention and rehabilitation techniques (Moseley et al. 1992, McGill et al. 1991). There was also found an activation increase of the square lumbar muscle (54%), in comparison with other muscles, during the isometric support performance in the elbows and soles, with the body parallel to the ground (McGill et al. 1991).

According to the abovementioned information, the significance of the present study is based on broadening the knowledge about the push-up exercise of the upper extremities and on helping in settling any conflicting reviews on this matter. Also, there is not a complete study that explores the field of push-ups, both electromyographically (including all the main muscle groups which participate in the exercise and not some of them) and mechanically. Although the push-up exercise is very popular, there are still arguments about which position aggravates less the area of the lumbar spine and which muscle groups are more activated in each position. This research studies the abovementioned issues and will complement the current scientific knowledge. The purpose of the present research is to evaluate the push-up exercise of the upper extremities biomechanically and operationally and to compare the muscle function in connection with the changes in position. Another purpose is to examine the inclination and the aggravation that is caused on the lumbar spine.

Material and Methods

Participants

The participants were 11 young males who exercised systematically on regular occasions, either on their own or in sports clubs. The selection of the sample was random regarding the type of their sports activity, their

physical condition and their previous experience with this exercise. All the participants had a Body Mass Index (BMI) less than 25 and they were healthy. Their anthropometric characteristics are shown on Table 1. Before the beginning of the exercises, the subjects were informed about the procedure and the purposes of the research and they filled an information sheet with their personal athletic and medical history. Anybody who had musculoskeletal and orthosomic problems in the past were excluded from the research. The acceptance of the terms, which was a prerequisite for the subjects, was established with their signed statement according to the process guide of the Research Committee of the Aristotle University of Thessaloniki (1997).

TABLE 1

Table 1. Anthropometric Characteristics	
	N=11
Height	177.7 ± 5.2
Weight	75.9 ± 6.1
Age	22.5 ± 2.4

Instruments

A dynamometry system (stabilometer) was used to evaluate the efforts and it recorded the forces and the shift of the Center of Pressure (COP). The signals from the sensors of this instrument were recorded directly into a Pentium IV electronic computer through a card used to convert the signal A/D Data Translation DT 9813. 100Hz were set as the frequency for the sampling.

An electromyographer (SX 230 Biometrics Ltd) was used to record the myoelectrical signal and it had bipolar surface stimulating electrodes that weighed 12 grams and adhered to the skin with double-sided stickers of a 1.25 cm diameter. Six electrodes were placed onto the biceps brachii muscle, the long head of the triceps brachii muscle, the middle deltoid muscle, the pectoralis major muscle, the serratus anterior muscle and the multifidus muscle. The electrodes were placed according to the SENIAM project (Surface Electromyography for the Non-Invasive Assessment of Muscles). Specifically, regarding the biceps brachii muscle, the electrode was placed in the middle of the line between the head of the brachii muscle and the cubital fossa. Regarding the triceps brachii muscle, the electrode was placed at 50% of the line between the posterior crista of the acromion and the olecranon, at two fingers' width lower from the middle of the line. However, regarding the deltoid muscle, the electrode was placed on the line set by the acromion and the lateral epicondyle of the elbow, on the greater bulge of the muscle. Regarding the serratus anterior muscle, the electrode was placed in parallel with the muscle fibers, below the axilla, anterior to the latissimus dorsi muscle between the ribs 4-6. Regarding the pectoralis major muscle, the electrode was placed in the middle of the distance between the anterior border of the axilla and the center of the sternum. Finally, regarding the multifidus muscle, the electrode was placed at the level of the 5th lumbar vertebra, between the 2nd vertebra and the posterior iliac spine. The frequency of data collection was at 1000 Hz per second. The signal of the electromyographer was recorded using the crude signal process with rectification and RMS.

An inclinometer was used to record the inclination between the torso and the horizontal level. The inclinometer was placed at the lumbar spine of the subjects. At the same time a digital metronome set the pace at which the subjects should perform the exercise.

Finally, a measuring rod (Seca 220) with a subdivision of 1 mm and an electronic scale were used to record the anthropometric characteristics of the participants.

Procedure

All the measurements were taken at the same time and at a steady room temperature of 23o–25oC. First of all, the record of each participant was taken (personal information, level of physical activity, history of injuries and diseases, etc) and then their anthropometric characteristics were collected.

Next, each participant repeated every type of the push-up exercise to ensure that he understood the way to perform it. The instructions on how to perform the exercise from each position correctly helped in a great way to reduce spontaneous movements during the exercise. Afterwards, the electrodes of EMG and the inclinometer were adjusted to each subject. Then, each subject performed the push-up exercise from six different starting points in the following order:

- Standard push-up position (position 1): The hands were placed right under the glenohumeral joint and the palms were parallel. The body lowered down to the ground until the elbows reached an inclination of 90o. It was important to place the shoulder, the ischium and the lateral malleolus in alignment. The feet were placed onto a steady metal parallelogram of the same height because the surface where the hands were placed on the stabilometer was 10 cm above the ground.

- Hands-apart position (position 2): The subjects were asked to maintain the same position, keep their body in alignment but place their hands 50% wider than the shoulders' width (Figure 1).



FIGURE 1

- Close hand position (position 3): The palms were placed in a “diamond-like” position where the index fingers and the thumbs were conjoined (Figure 2).



FIGURE 2

- Elevating the feet above the hands position (position 4): The feet were placed on a steady surface which was 30 cm above the ground and this position resembled the standard push-up position. The difference in the final height from the hands was 20 cm.
- Knee push-up position (position 5): The hands were placed in the same way as in the standard push-up position; yet, the subject was supported on his knees. The pelvis and the torso lowered down simultaneously.
- Elevating the hands above the feet position (position 6): The hands were placed onto a surface that was 30 cm from the ground. The feet stayed on the metal parallelogram like in the standard push-up position. The difference in the final height from the feet was 20 cm.
- The subject had to perform three repetitions from each starting point while there was a one-minute break between each exercise. During the exercises a metronome was used to set the pace at which the subjects had to perform the exercise. The pace was set at one second for the eccentric phase, one second for staying at the final position and one second for the concentric phase.

Statistical Analysis

The statistical analysis of the data was done with the statistical package S.P.S.S. version 13. The statistical method two-way Multiple Analysis of Variance (two-way M ANOVA) was used for repeated measurements. The average, the typical deviation and the maximum value of all the dependent variables were estimated. Post hoc test (Bonferroni) was used to estimate the differences among the mean values. $P < 0.05$ was set as a level of importance.

Results

The subject started the exercise from a neutral position with extended elbows; then, during the eccentric phase he lowered down until his elbows inclined at about 90°; he stayed at this position for one second and he completed the movement when he came back to his initial position. Each exercise had three repetitions. In the following figure (Figure 3), there is a typical graph of the electromyographic activity of all the muscles that were studied.

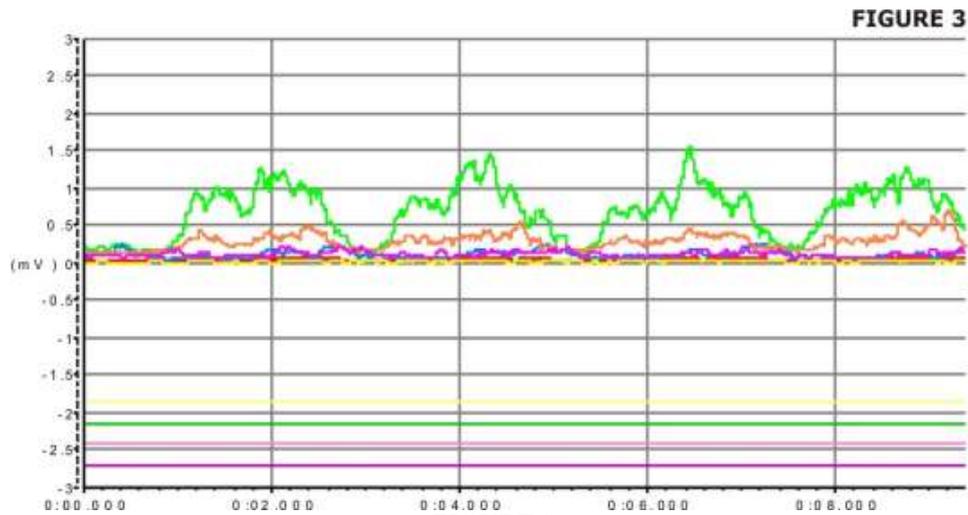


FIGURE 3

The following graph (Figure 4) shows the shift of the COP in the left and the right arm during a random attempt.

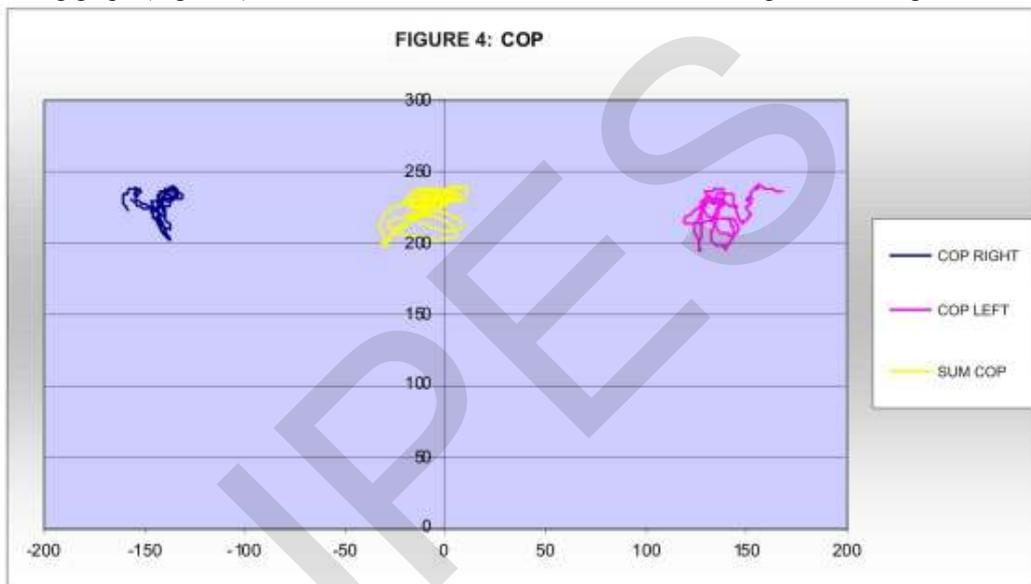


FIGURE 4

Results of Dynamic Analysis

There were no statistically important differences in the rates of force application for both the left and the right upper extremity. However, there were some differences in the vertical forces of the left and right arm in some positions. The following graphs show the mean values and the typical deviations of the vertical forces of the two hands in all six positions (Figures 5-6).



FIGURE 5



FIGURE 6

The post hoc test (Bonferroni) showed differences among the mean values of the vertical forces during the performance of position 6 ($p < 0.05$) compared to the other positions. Specifically, the mean value of the vertical force of the right upper extremity was statistically and significantly lower ($p < 0.05$) when the upper extremities were placed higher than the lower extremities (position 6) compared to the other positions (Graph 2). The mean value of the vertical force of the left upper extremity (Graph 1) in position 6 was also significantly lower ($p < 0.05$) compared to the other positions. Moreover, regarding the left upper extremity, lower vertical force seemed to be applied in position 3 as well ($p < 0.05$) compared to the other positions. However, the average vertical force was greater on the left upper extremity in position 3 compared to position 6, even though in both cases there was a lower vertical force compared to the other positions.

Regarding the Rate of Force Development (RFD), there were some statistically important differences. RFD was higher ($p < 0.05$) for the left upper extremity during the performance of the exercise in position 1 compared to position 3 (Figure 7). Also, there was a statistically important difference for the right upper extremity in position 6 where there was a lower RFD compared to position 4 (Figure 8).

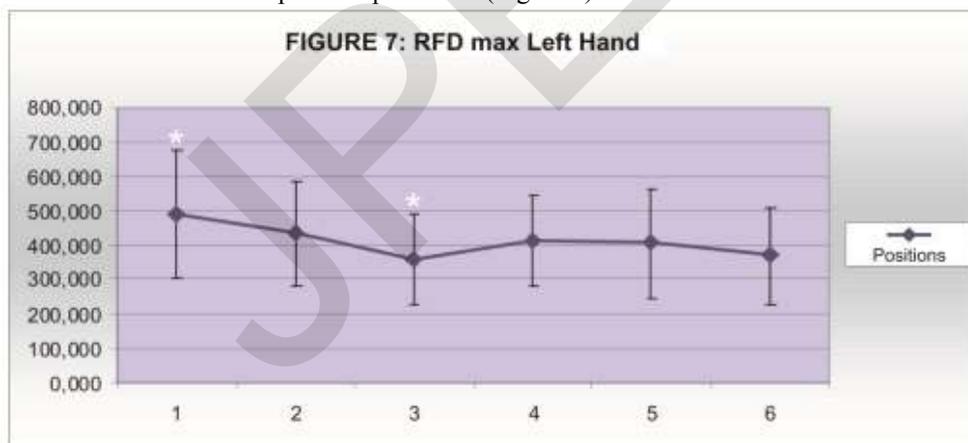


FIGURE 7

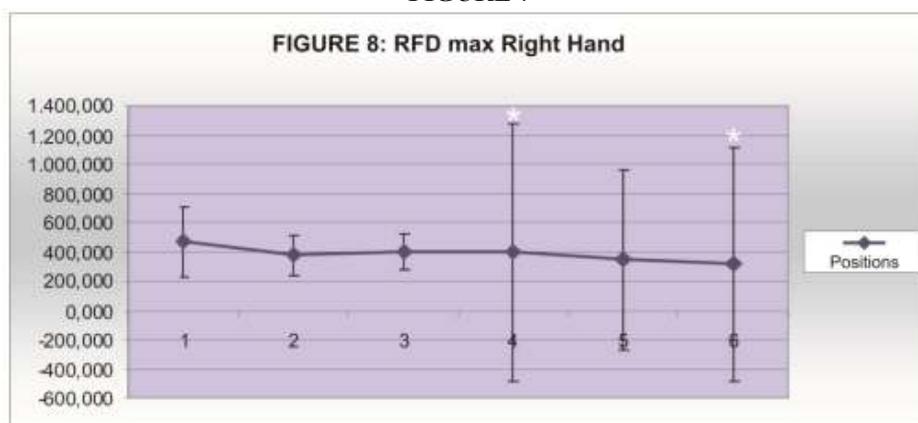


FIGURE 8

No statistically important differences were noticed regarding the shift of the COP during the various positions of the push-up exercise when analyzing the kinematic parameters.

However, Figure 9 shows that the shift of the COP in the longitudinal axis X was greater than the shift in the lateral axis Y in all positions. Finally, it is noticed that the total shift of the COP (X, Y) was smaller during the exercise in position 3, even though the support base was smaller than the support base in other positions.

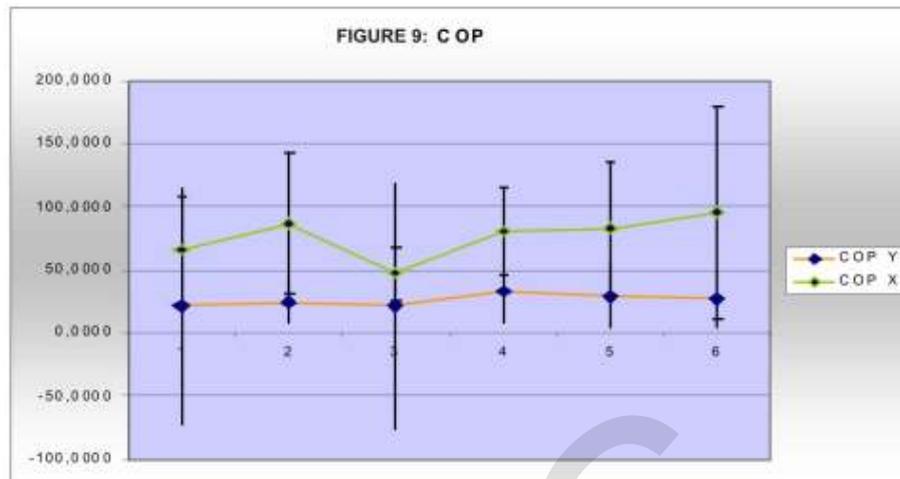


FIGURE 9

Qualitative Observation of Weight Distribution

All the subjects of the sample were right-handed. They stated that they used their right arm in most of their daily activities. The observations showed that all the participants applied a higher percentage of average relative force on the left upper extremity in all positions (Figure 10).

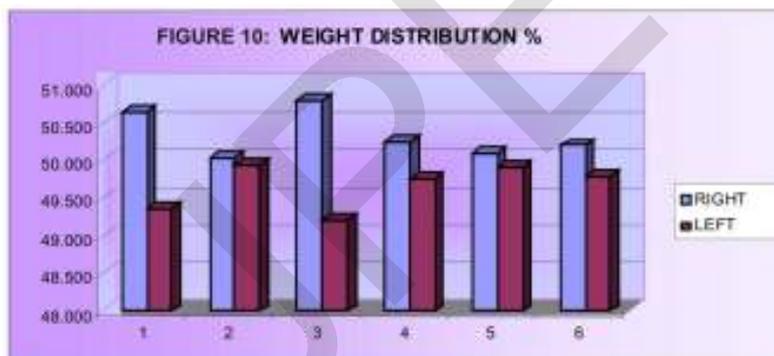


FIGURE 10

Moreover, when in the end the participants were asked to estimate which position was the most difficult for them, they all stated that position 3 was the most exhausting position; one participant could not even complete the set of three repetitions in this position. The same graph shows that in position 3 the subjects tended to strain most the upper extremity which they considered more dexterous. Finally, the results of the inclinometer did not show statistically important differences in the inclination of the torso during the push-ups from various starting points given that position zero was considered to be the starting position before any exercise.

Results of the Electromyographer's Analysis

The statistical analysis of the data that was recorded on the electromyographer did not show any statistically important differences in the activation of the biceps brachii muscle, the deltoid muscle, the serratus anterior muscle, the pectoralis major muscle and the multifidus muscle that could be correlated with the various starting points in the performance of the push-up exercise. However, regarding the triceps brachii muscle, there were statistically important differences. Specifically, the maximum value of the activation of the triceps brachii muscle (Figure 11) showed a statistically important difference ($p < 0.05$) during the performance of the push-ups from position 1 and position 3 compared to position 5 ($p < 0.05$).

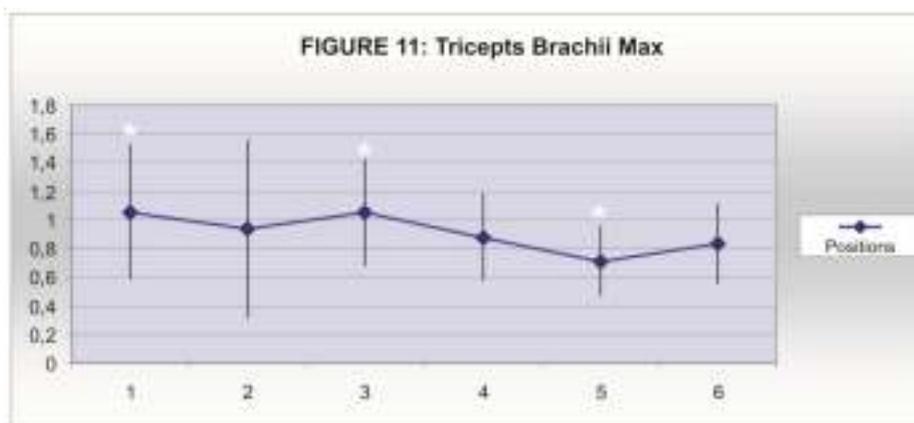


FIGURE 11

The mean value of the triceps brachii muscle shows statistically important differences in position 5 where it has the lowest value ($p < 0.05$) compared to the other positions (Figure 12).

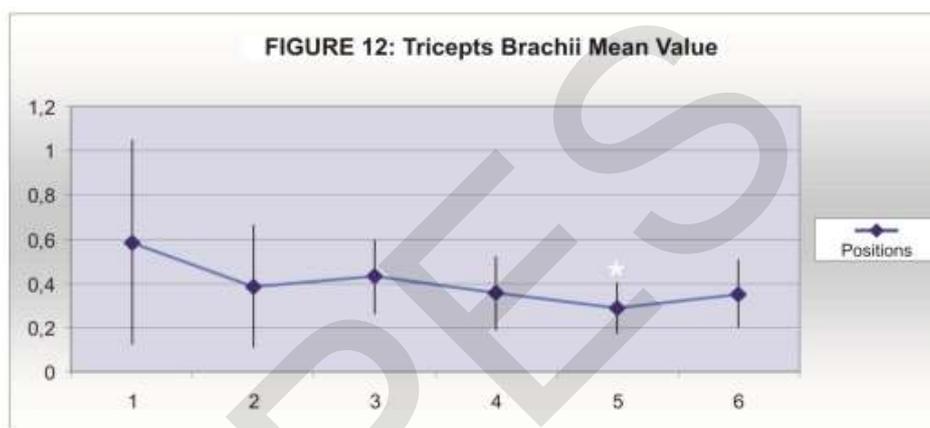


FIGURE 12

Generally, in position 5 there was a smaller activation of the triceps brachii muscle compared to the other positions. Finally, there was a smaller shift of the CPO both in the longitudinal axis X and the lateral axis Y in position 1 and position 3 where there is the largest activation of the triceps brachii muscle.

Discussion

The study is restricted to a steady surface unlike other studies which compare steady and unsteady support surfaces (Freeman et al. 2006; Donkers et al. 1993; Lehman et al. 2007; Ludewig et al 2004; Lehman et al. 2006). This is not a restriction since most research does not include all muscle groups and does not examine the differences in the muscle activation in same surfaces with different support. Most research compares only two surfaces. Also, it is important to observe whether the changes in the placement of the upper extremities affect the result of muscle activation without any rotation and projection of the scapula, as other authors distinctively mention (Freeman et al. 2006; Decker et al. 1999; Ludewig et al 2004; Lehman et al. 2006).

The present research showed that there are changes in muscle activation, RFD, the shift of the COP and the vertical forces between the left and right upper extremity. This is probably due to which hand each subject tends to use in order to maintain his balance. Even though there is not any research that mentions the use-prevalence of one upper extremity in the push-up exercise, the highest distribution of weight on the right hand in all positions remains a mystery.

Moreover, even though it was proven that in position 3 there is a smaller shift of the COP, both in the longitudinal axis X and the lateral axis Y, and a maximum value of the triceps brachii muscle's activation, yet it is noticed a lower mean value of vertical force and a lower RFD for the left upper extremity (where there was a smaller distribution of weight) in position 3 compared to the other positions. This is probably due to the difficulty in performing the exercise as the participants stated. Based on that, we reach a conclusion that position 3 can activate the triceps brachii muscle to its maximum but this activation is slow. That means that the performance of the exercise in this position is not recommended in cases where the aim is to improve the muscle strength. However, it can be used to strengthen the triceps brachii muscle and it is likely to provide good results.

Position 1 offers the greatest RFD and at the same time the largest activation of the triceps brachii muscle, at least for the left upper extremity. This is probably due to the anatomically more correct upright position of the glenohumeral joint and the cubital fossa where the triceps brachii muscle actuates and stabilizes these joints (Lehman et al. 2006). Therefore, position 1 seems to be the most effective regarding both muscle strength and muscle force, compared to the other positions, when the push-up exercise is performed on a steady support surface.

Measurements, which compared mostly steady and unsteady support surfaces, note that the triceps brachii muscle is one of the muscles that are affected more than others when they are on an unsteady surface. The main reason for that is that the triceps brachii muscle is a two-joint muscle which has stability and movement both in the glenohumeral joint and the cubital fossa compared to the pectoralis major muscle, which is a one-joint muscle and its activity is not affected by the type of surface (Donkers et al. 1993; Lehman et al. 2006) consider push-ups an excellent exercise since the maximum torque during resistance represents more than 50% of the maximum force of the triceps brachii muscle and such torque could exceed the 70% of the maximum force with further adjustment of the hand position. However, no other research studies the activity of the triceps brachii muscle in essence.

Regarding the other muscle groups, there were no differences in the muscle activity during the shift of the starting point of the exercise. Other researchers agree with these findings, including the ones about the pectoralis major muscle, even though the difference in the hand position was not studied, which showed no change in its activation even when the type of surface changed (Lehman et al. 2007; Drake et al. 2006). Regarding the serratus anterior muscle, it is mentioned that there is a significant activation of this muscle during the push-ups compared to other exercises only for the shoulders, even though there is consensus about the importance of this muscle since it is the main locomotive muscle of the scapula (Decker et al. 1999; Lehman et al. 2007; Ludewig et al 2004; Oliveira et al 2007). Regarding the trapezius muscle, it is mentioned that its activation does not approach the limits of an essential muscular activity during the push-ups and that is also noticed in the present study (Ludewig et al 2004; Lear et al. 1998; Moseley et al. 1992). The activation of the biceps brachii muscles during the push-ups did not interest many researchers. It has been proven that the position of the body, the upper and lower extremities and the stability of the support surface do not change the activation of these muscles (Lehman et al 2007; Oliveira et al 2007). Finally, regarding the deltoid muscle, there are references only to the anterior part of the muscle, while electrodes were placed on the middle deltoid muscle in the present study (Decker et al. 1999; Oliveira et al 2007).

In position 6 there is a smaller mean value of the vertical force both for the left and the right upper extremity and there is also a low RFD for the right upper extremity. This exercise might be easier to perform and that is why it precedes the standard push-up position in protocols of rehabilitation from injuries (Ludewig et al 2004; Lehman et al. 2007). However, position 6 is not the most appropriate position in cases where the aim is to strengthen the muscles and increase the muscle force.

Finally, the low activation of the multifidus muscle in all positions and the lack in altering the torso's inclination that were recorded on the inclinometer show that the correct body position during the performance of the exercise and the maintenance of a correct body posture do not affect the mechanical function of the lumbar spine and this area is not further stimulated. As McGill (1991) highlighted, understanding the mechanism of the push-ups performance can lead to better prevention and rehabilitation techniques. Moreover, the small number of repetitions gave all subjects the possibility to perform the exercises comfortably.

Conclusion – Proposals

Summarizing, we can say that the exercise of bendings – extensions of the upper limbs activates many muscular groups, such as the brachial triceps muscle, the major pectoral muscle and the anterior cogged muscle. However, apart from the triceps, the performance of the exercise in a stable surface, from whichever starting point, doesn't affect the alteration of the rest muscles' activation significantly. At the same time, if we keep the trunk straight and there is control and stabilization, the lumbar degree is not affected, thus the exercise is judged as improper for people with pains or sensibilities in this area. Also, an easier performance, as far as the first and the last position is concerned, is not at a disadvantage, referring to the muscular activity, to a harder one.

Considering the constrictions and weaknesses of the present study, it would be good to study the same issue with a larger and more varied sample, such as a sample that includes females or even people who have not had any form of exercise compared to the ones who have. It would also be interesting to examine the type of surface in relation with the different support position of the upper extremities.

Estimating that most people believe that, the increase of the difficulty implies the necessary increase in the result, it might be good to study the issue furthermore, through a mediatory program.

It might be good to study this issue in a greater time frame through an interventionist program because, as most people believe, an increase in the difficulty leads to a necessary increase in the result, even though the present study has proven that the ideal position is the standard push-up position.

This study enabled us to apprehend that simple movements which are widely used have been remotely examined and the field of further research is large.

The results of the present study could be useful in areas and recovery places so that the push-up exercise would be included in their protocols.

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