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EFFECT OF ELBOW ANGLE ON TRICEPS BRACHII AND PECTORALIS MAJOR MUSCLE ACTIVITY DURING PARALLEL BAR DIP

VPLIV KOTA V KOMOLČNEM SKLEPU NA MIŠIČNO AKTIVNOST TROGLAVE NADLAKTNE MIŠICE IN VELIKE PRSNE MIŠICE MED SKLEKOM NA BRADLJI

ABSTRACT

The parallel bar dip is one of the most commonly used calisthenic exercises. However, a recommended elbow angle in terms of activation patterns has not yet been studied. The aim of this study is to examine the activation values of the pectoralis major and triceps muscle groups during parallel bar dip at different elbow angles. Ten male volunteers (age: 25.1 ± 3.9 years) with regular exercise habits participated in the study. During the parallel bar dip, the pectoralis major, lateral triceps and long triceps muscles were examined at elbow angles of 75°, 85° and 95°. The movement was standardized using the metronome (60 beats.min$^{-1)}$ and evaluated in three phases (eccentric = 2 seconds, isometric = 1 seconds, concentric = 2 seconds). There was no statistically significant difference between the angles for pectoralis major ($p>0.05$). Significant differences were observed in triceps muscle groups, especially in favor of 75° in the isometric phase ($p<0.05$). The greatest activation in terms of phases was seen in concentric contraction for all muscles. This research has shown that the reduction of the elbow flexion angle has a positive effect on the activation of triceps muscle group. However, since there are some methodological limitations (such as biomechanical markers), it can be said that future research should improve these findings.

Keywords: calisthenic, elbow angle, electromyography, fitness

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IZVLEČEK

Sklek je ena najpogosteje uporabljenih kalisteničnih vaj. Vendar priporočeni kot v komolčnem sklepu v smislu vzorcev aktivacije še ni bil raziskan. Namen te študije je preučiti velikost aktivacije mišičnih skupin troglave nadlaktne mišice in velike prsne mišice med sklekom na bradlji pod različnimi koti v komolčnem sklepu. V raziskavi je sodelovalo deset moških prostovoljcev (starost: 25,1 ± 3,9 let), ki so se redno ukvarjali s telesno vadbo. Med sklekom so bile opazovane velika prsna mišica, lateralna in dolga troglava nadlaktna mišica pod kotom 75°, 85° in 95°. Gibanje je bilo standardizirano z metronomom (60 utripov.min-1) in ovrednoteno v treh fazah (ekscentrično = 2 sekundi, izometrično = 1 sekundo, koncentrično = 2 sekundi). Pri veliki prsni mišici ni bilo statistično značilne razlike med koti ($p > 0,05$). Značilne razlike smo opazili pri mišičnih skupinah troglave nadlakne mišice, predvsem pri kotu 75° v izometrični fazi ($p < 0,05$). Največjo fazno aktivacijo smo opazili pri koncentričnem krčenju vseh mišic. Ta raziskava je pokazala, da zmanjšanje kota v komolčnem sklepu pozitivno vpliva na aktivacijo troglave nadlaktne mišice. Ker pa obstajajo nekatere metodološke omejitve (kot so biomehanski označevalci), lahko rečemo, da bi morale prihodnje raziskave izboljšati te ugotovitve.

Ključne besede: kalistenika, kot v komolčnem sklepu, elektromiografija, fitnes

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INTRODUCTION

The concept of "Kàlos + Sthénos" (calisthenic), which means beautiful force in ancient Greece, has been preferred for many years for the purpose of developing power. It is considered that there are important reasons for choosing calisthenic resistance training such as being economical, not requiring special area and functionality (Tsourlou, Gerodimos, Kellis, Stavropoulos, & Kellis, 2003; de Souza Santos et al., 2015). In a recent article investigating European 2020 fitness trends, it is seen that body weight exercises are in the 3rd place in the list (Batrakoulis, 2019). It is stated that calisthenic exercises also show significant improvement on parameters that affect daily life such as posture, strength and body composition (Thomas et al., 2017). Calisthenic exercises have been examined in surface electromyography (sEMG) studies (Hamlyn, Behm, & Young, 2007). Most of the time in these studies, the aim is to interpret the activation value in terms of the effectiveness of exercise (Escamilla et al., 2006).

One of the commonly preferred calisthenic exercises is the parallel bar dip movement (Coyne et al., 2015). Dip movement is performed as a closed kinetic chain and generally performed for triceps brachii and pectoral muscle group development. Despite the popularity of the dip exercise, it has been stated that it has not been studied in detail, especially in terms of kinematics (McKenzie, Crowley-McHattan, Meir, Whitting, & Volschenk, 2021). When the literature is reviewed, a study has been found that compares the triceps brachi and pectoralis major activation values during different dip exercises (Bagchi, 2015). On the other hand, there has been no study investigating the effect of elbow angle difference on sEMG activity during the same dip motion. Being informed about the activation patterns of the muscles involved during the dip exercise allows the exercise participants to perform this movement more consciously. In this way, individuals who have gained exercise awareness can have more rational expectations. At the same time, the differences in joint angles affect the neuromuscular adaptation process of the muscle and this effect changes the number of sarcomeres to optimize the force–length relation at the molecular level (Noorkõiv, Nosaka, & Blazevich, 2014; Burkholder & Lieber, 1998). Therefore, activation analysis at different elbow angles is thought to be important both for contributing to the influence of joint angle-specific training and creating awareness for exercise participants.

It is thought that differences in elbow angle during dip exercise may affect the efficiency of the movement. Yang et al. found that the angle change in the elbow joint significantly affected the activity and strength levels of the elbow flexor and extensor muscles (Yang et al., 2014). In another study, it was stated that different elbow angles caused a significant difference on elbow flexor muscle activity in pulley weight exercise (Kang, Seo, Park, Dong, Seo, & Han, 2013). Since the change in the elbow angle causes a change in the moment arm length, it directly affects the muscle activity (Kaufman, An, & Chao, 1989). At this point, there are studies that determine the relationship between stretch length and strength performance at different joint angles and suggest an optimal angle (Yamauchi & Koyama, 2019; Sharma, Das, Tayade, & Deepak, 2021). Therefore, developing optimal angle strategies specific to exercises can maximize the efficiency of the exercise.

This research has the potential to contribute theoretically and practically to exercise participants. In the study, it was aimed to determine the sEMG activity of triceps brachii (lateral and long head) and pectoralis major muscles during parallel bar dip movement applied at different elbow angles. The hypothesis of this study was that the difference in elbow angle during parallel bar dip movement has a difference in sEMG activity in the triceps brachii and pectoralis major muscles.

METHODS

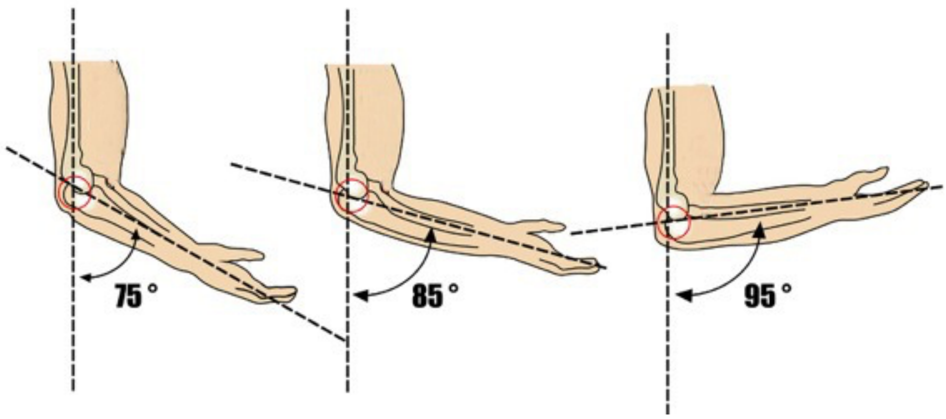
Participants

Ten male volunteers with regular exercise habits (age: 25.1 ± 3.9 years; 180.6 ± 7.09 cm; body weight: 76.5 ± 8.30 kg; body fat percentage: 10.12 ± 2.24%; body mass index: 21.13 ± 7.71 kg / m^2) was included. The volunteers were informed 48 hours before testing to avoid any additional resistance training. The volunteers were instructed to sustain their normal diet, hydration, and sleeping habits throughout the study. The Local Ethical Committee for the Protection of Human Participants approved the research (2017/19) and it complied with the ethical requirements asserted by the Helsinki Declaration of 1975. Prior to being given any data of study procedures, all volunteers were informed and signed a consent form and completed a health history questionnaire.

Parallel Bar Dip

Parallel bar dip was primarily examined in 3 phases. These were determined as eccentric (descending), isometric (static) and concentric (ascending) phases. Movement started with the elbow in the full extension position (0° = full extension) and continued towards the eccentric contraction. The 3-D myomotion segmental motion system was used to determine the difference in elbow angle (Noraxon U.S.A. Inc., Scottsdale, Arizona, USA). Three different elbow angles were examined in the study (Figure 1) and metronome (60 beats.min^{-1}) was used to optimize movement speed during exercise. During the parallel bar dip movement, the participants completed the eccentric and concentric phases in 2 seconds and the isometric phase in 1 seconds, in accordance with the metronome sound. The specified durations were chosen to keep the natural flow of the movement intact and to examine the time under tension in the most appropriate way. Participants were asked to keep the trunk as straight as possible and keep their elbows close to the trunk while descending to the targeted angle during the dip movement. Before the measurements, all participants are included in the familiarization process consisting of 4 sessions. The purpose of this process was to enable the participants to act in harmony with the metronome during the movement.

Figure 1. Elbow angles during parallel bar dip.



Surface Electromyography Procedure

Triceps brachii lateral head (LaT), long head (LoT) and pectoralis major (PM) muscles sEMG activities were evaluated during the parallel bar dip exercise from the dominant sides of the participants. Before the electrodes were positioned on each muscle, the skin was prepared by shaving, abrading, and cleaning with isopropyl alcohol wipes to reduce skin impedance values. Following the skin preparations, circular bipolar Ag-AgCI surface electrodes (Noraxon Dual Electrodes, Noraxon USA, Scottsdale, Arizona; diameter, 1 cm; interelectrode distance, 2 cm) were placed on the volunteer’s dominant side (Anderson & Behm, 2005). Maximal Voluntary Contraction (MVC) measurements were applied before the dip movement to normalize the data. Five-second MVC was performed three times (with a two-minute rest between contractions) for the recruited muscles, while the individuals performed a MVC against manual resistance provided by a trained expert (Harput, Soylu, Ertan & Ergun 2013).

Triceps Brachii Long and Lateral Head (MVC): The shoulder and elbow flexed to 90 degrees while the sEMG was recorded during resisted elbow and shoulder extension (Lehman, MacMillan, MacIntyre, Chivers, & Fluter 2006). *Triceps Brachii Lateral Head (Electrode placement):* Electrodes need to be placed at 50 % on the line between the posterior crista of the acromion and the olecranon at 2-finger widths lateral to the line (Silva et al., 2014). *Triceps Brachii Long Head (Electrode placement):* About 3 cm medial and on 50% on the line between acromion and olecranon (Saeterbakken et al., 2013). *Pectoralis Major (MVC):* With the elbow flexed 90 degrees and the shoulder abducted 75 degrees the subject performed a maximal palm press while the muscle activity was recorded (Lehman, MacMillan, MacIntyre, Chivers, & Fluter, 2006). *Pectoralis Major (Electrode placement):* The PM electrode was placed at the midpoint of the distance between the sternal notch and the axillary fold (Youdas, Budach, Ellerbusch, Stucky, Wait, & Hollman, 2010).

Raw sEMG signals were collected with a sampling rate of 1500 Hz using an 8-channel wireless telemetry system (Noraxon Desktop DTS) and were analyzed by MyoMuscle MR 3.10 Clinical Applications software (Noraxon Telemyo, Noraxon USA, Scottsdale, Arizona). After visual inspection and erroneous signal elimination, all sEMG raw signals were first 20-500 Hz Butterworth bandpass filtered and then RMS-filtered with a 100 ms time-window for movement artefact rejection and signal smoothing, respectively (Yi, Brunt, Kim, & Fiolkowski, 2003; Krishnamoorthy & Latash, 2005). The maximum value of the three root mean square (RMS)-filtered MVC signals is calculated for each muscle, and each RMS-filtered sEMG signal of dip activity is represented as %MVC by dividing the RMS-filtered sEMG activity to the its maximum MVC value (Mok et al., 2015). Then, the mean values of the normalized activity signals (Phases 1, 2, and 3) are used for statistical analysis. The term sEMG activity is used for the “mean %MVC normalized phase values” for simplicity.

Statistical Analysis

Findings were analyzed using GraphPad Prism 7.0 software (GraphPad Software Inc, San Diego, California, USA). The data distribution was assessed by the Shapiro–Wilk test and homogeneity of variance using Levene’s test. The repeated measures were used to determine angle differences. If there was a difference between angles, Bonfferroni multiple comparison tests were performed according to the significance level. Significance level in the research was determined as $p<0.05$.

RESULTS

Table 1 show the comparisons of normalized EMG amplitude values (mean % MVC) from concentric, isometric and eccentric muscle actions. There was no statistically significant difference in the PM muscle ($p> 0.05$). On the other hand, it was determined that the activation of the triceps muscle group changed significantly with the different angles in the isometric phase ($p<0.05$) Also, the highest activations were detected in the concentric phase (PM:>38%; LaT:>50%; LoT:>40% of MVC).

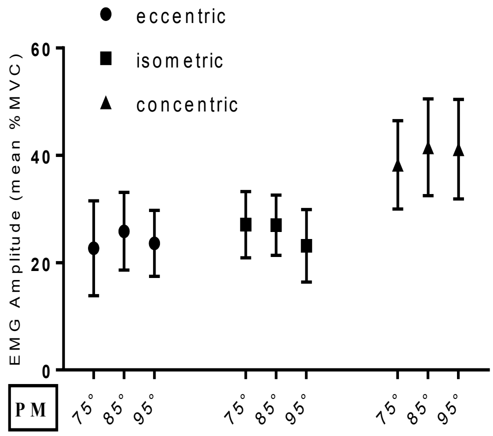
Table 1. The mean normalized sEMG activation values of muscles (mean % MVC).

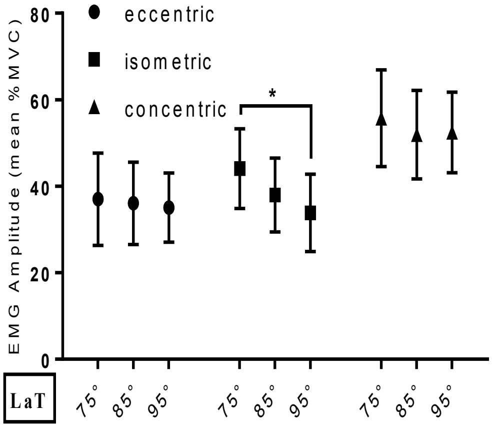
Muscles	Dip Phases	Elbow Angles			$F_{(2,18)}$	p
		75°	85°	95°		
PM	Eccentric	22.7	25.85	23.61	1.632	.223
	Isometric	27.08	26.99	23.13	2.441	.115
	Concentric	38.23	41.05	41.14	1.673	.216
LaT	Eccentric	36.99	36.05	35.04	.743	.490
	Isometric	44.07	37.96	33.85	4.799	.021*
	Concentric	55.7	51.92	52.44	1.336	.288
LoT	Eccentric	26	27.57	25.6	.811	.460
	Isometric	31.77	26.53	18.93	28.995	.001**
	Concentric	41.76	41.23	40.31	.173	.843

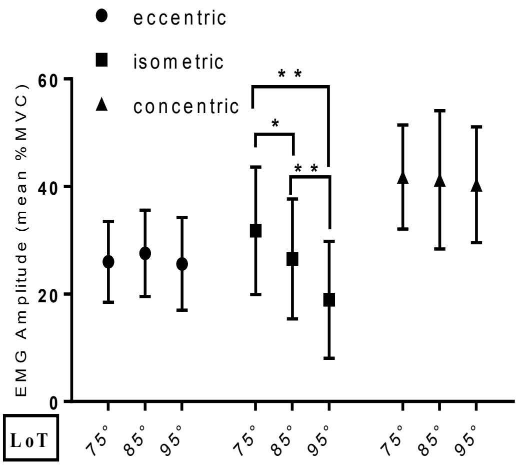
*p<0.05; ** p<0.01; PM: Pectoralis major; LaT: Lateral triceps; LoT: Long triceps

Figure 2 show how activation values are affected by changing elbow angles. While no significant difference was found in the PM muscle, a finding in favor of 75° was observed in the isometric phase of the LaT muscle compared to 95°. A statistically significant difference was found in the LoT muscle when comparing 75° with the other two elbow angles. Finally, a significant difference was observed between the 85° and 95° elbow angles in the isometric phase. In the study, it was seen that the difference in elbow angle had a significant effect in the triceps muscle group. There was a negative interaction between the elbow joint angle and the activation values for the triceps muscle group in the isometric phase.

Figure 2. sEMG activity of the same muscles at different angles (mean % MVC).







(PM: Pectoralis Major; LaT: Lateral triceps; LoT: Long Triceps)
*Single asteriks indicate significant differences at the $p<0.05$ level, whereas
**double asteriks indicate significant differences at the $p<0.01$ level.

DISCUSSION

Parallel bar dip movement was examined as eccentric, isometric and concentric phases. In our study, it was observed that the decrease in the degree of flexion in the elbow joint may be an advantage in terms of muscle activation. In the study, a significant difference was found in the triceps muscle group in favor of the 75° elbow angle in the isometric phase.

There are studies in the literature examining the relationship between joint angle and muscle activation values (Onishi, Yagi, Oyama, Akasaka, Ihashi, & Handa, 2002). However, to our knowledge, there is no study examining the normalized sEMG activities of the triceps and pectoral muscle groups during parallel bar dip exercise using the angles in this study. Komi et al. examined the strength and sEMG power spectrum values of the biceps brachii, brachioradialis, and triceps brachii muscles during eccentric, concentric and isometric movements (from 55° to 165° in the eccentric actions and from 165° to 55° in the concentric actions) and found that the highest activation was in concentric contraction at 110° elbow angle (Komi, Linnamo, Silventoinen, & Sillanpää, 2000). Yang et al. compared muscle strength and activation at 56°, 70°, and 84° elbow joint angles. In the study, biceps muscle strength and activation were found to be the highest at 56° elbow angle and 84° elbow angle for triceps (Yang et al., 2014). Doheny et al. analyzed the sEMG measurements of biceps, brachioradialis and triceps muscles during isometric flexion and extension performed at eight elbow angles. In the study, it was determined that the difference in elbow angle does not have a significant effect on the sEMG amplitude values, but causes a significant difference on the strength values (Doheny, Lowery, FitzPatrick, & O'Malley, 2008). At this point, it can be said that due to the change in the moment arm, the joint angle may have a direct effect on the force, but speculative results can be obtained for motoneuron excitation patterns. The reason for this can be shown as the electrode displacement during dynamic movements, morphological change of the muscle and the contractible units affected by this situation (Farina, Merletti, Nazzaro, & Caruso, 2001). In the study, the highest activation values were observed for the triceps muscle group in the isometric phase when the elbow flexion angle was the smallest (75°). In parallel with the findings, it is stated that as the length of the muscle increases (eccentric contraction), the activation value will decrease (Enoka, 1996). This is explained by the fact that lower levels of voluntary activation are required by the nervous system in order to achieve a certain muscle strength in eccentric contractions.

In the study, the determination of the greatest activation value at 75° elbow flexion angle can be explained by several possible mechanisms. The decrease in the activation value with the increase of the eccentric contraction length may be one of them (Enoka, 1996). In a study supporting this situation in the literature, it was determined that triceps brachii muscle activation was higher in partial range of motion (from 45° to 90°) exercise than in full range of motion exercise (from 0° to 90°) (Goto et al., 2019). In another study, elbow joint angle was examined during bench press exercise and it was determined that the highest triceps brachii EMG_{PEAK} value was in the middle of the concentric phase (Lacerda et al., 2020). However, it has been stated that it may be wrong to associate the difference in activation only with the muscle length (Extras, Unread, & Mode, 2005). Therefore the architectural structure and moment arm of the muscle should be known in order to calculate the force and moment generating capacity of the muscle (Murray, Buchanan, & Delp, 2000). In a study in which the glenohumeral joint was fixed, it was determined that the triceps muscle has a long moment arm and stabilizes the force in a wide range of motion (30°-120°) (Murray, Buchanan, & Delp, 2000). However, the dip movement is a rare exercise in which the glenohumeral joint is reached to the end range glenohumeral extension (McKenzie, Crowley-McHattan, Meir, Whitting, & Volschenk, 2021). Therefore, it should not be compared with tests that examine elbow joint difference by keeping the shoulder angle constant, or with movements with limited glenohumeral joint extension such as bench press and push-up. The increase in elbow flexion angle during movement may lead to more activation of the latissimus dorsi, pectorals and deltoids, which play a synergistic role. In this case, the increased extension, abduction and shortening of the moment arm in the glenohumeral joint may cause an inhibition for the triceps. However, there are no studies that reported the EMG activation values throughout the entire movement of the dip exercise at the different elbow angles, so the reasons mentioned were interpreted according to the findings obtained in our research.

In the study, the highest activation for all muscles was in the concentric phase. In various studies, it has been observed that the activation values of the concentric phase are significantly higher than the eccentric phase (Grabiner & Owings, 2002; Linnamo, Strojnik, & Komi, 2002). The reason for this is that both contractions have different neurological and biomechanical properties (Nakazawa, Yano, Satoh, & Fujisaki, 1998). It has been stated that especially during concentric contractions, stronger stimulation occurs and greater activation values are seen compared to eccentric contractions (Selseth, Dayton, Cordova, Ingersoll & Merrick, 2000). It has been determined that the change in the diameter of the elongated muscle fiber in the eccentric contraction decreases the conduction velocity (Trontelj, 1993). In addition, it has been stated that some neural inhibition mechanisms come into play during eccentric contractions and produce negative stress-reducing feedback (Westing, Seger, & Thorstensson, 1990). These rational explanations may explain why greater activation is seen in the voluntary concentric contraction. In this study, the findings obtained in the concentric phase have moderate (20-40% MVC) and high (41-60% MVC) activation degrees according to the classification system created to interpret sEMG studies (DiGiovine, Jobe, Pink, & Perry, 1992). Therefore, dip movement can be considered as an effective exercise strategy in terms of activation values.

Having the activation values at the desired levels does not mean that it can be considered safe. There is a case study examining the rupture of the pectoralis major muscle due to dip movement (Carek & Hawkins, 1998). Although this type of injury occurs very rarely due to dip movement, it clearly shows that the movement may involve a risk. For safety, the primary step may be the elbow angle. The elbow flexion angle and the eccentric contraction rate of the pectoralis major muscle show a positive relationship. At the same time, with the anterior translation of the humeral head, the glenohumeral joint will be under pressure and may cause injuries (McKenzie, Crowley-McHattan, Meir, Whitting, & Volschenk, 2021). In this study, the greater activation obtained at an elbow angle of 75° can be used as a strategy for both muscular development and injury avoidance in terms of dip movement.

There are some limitations to the research. One of the factors that can change the activation of the muscles may be the angle of the trunk. Because in the case of parallel bar dip, the angle of the trunk affect the moment arm and torque. This change the load applied to the involved muscles, resulting in differences in activation. Although the dip movement is applied to the participants in a certain standard, it is thought that the angle of the trunk can also affect the activation patterns. Another important deficiency is that the distance of the humerus to the trunk is not taken into account during movement. It has an effect directly on activation by affecting the shoulder angle. It can be said that a comprehensive biomechanical model is needed to solve all these problems. However, the research is unique as it compares the activation of muscles considered prime movers during dip movement.

CONCLUSION

In this study, activation values in favor of less elbow angle were observed in the triceps group in terms of the isometric phase. This finding is acceptable due to the expected negative relationship between the lengthening of the muscle and the activation values. However, fundamentally important mechanisms such as moment arm length and trunk angle, which may directly affect activation values, have not been investigated in the study. Therefore, further studies are needed to include more comprehensive biomechanical markers.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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