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# Dynamic and Electromyographical Analysis in Variants of Push-Up Exercise

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**Abstract.** Gouvali, M.K., and K. Boudolos. Dynamic and electromyographical analysis in variants of push-up exercise. *J. Strength Cond. Res. 19(1):146–151. 2005.*—The purpose of the study was to record dynamic and muscular modifications during push-up exercise variants (EV). Eight healthy men performed 6 EV of push-ups: normal, abducted, adducted, posterior, anterior, and on knees. Ground-reaction forces were recorded with a force plate while surface muscular activity with electrodes on triceps and pectoralis major. Significant differences ($p < 0.05$) existed for most vertical force variables but not for anteroposterior force and time variables. The initial load relative to body weight was 66.4% at the normal position, while only 52.9% at the on-knees EV. Muscle activity was less during the on-knees EV for both muscles. At the posterior EV, pectoralis major was activated higher than normal; however, triceps were activated lower than normal. Dynamic behavior and muscle activity were significantly altered between push-up EV. Instructions for push-up exercises should be followed carefully because dynamic and muscular challenge is altered when hands are differently positioned.

Key Words. pectoralis major, triceps, ground reaction force, strength training, exercise selection

## Introduction

Push-up exercises are very popular in upper-body strengthening programs. They are closed kinetic chain exercises, for which pectoralis major and triceps brachii are the principle acting muscles. Push-ups are loaded by the body weight but are usually compared with the movable-load bench press exercise (3). The popularity of the push-up exercise arises because it is easily learned, requires no equipment, and is adaptable to different fitness levels.

This adaptability is achieved by the different postures (termed exercise variants [EV]) that can be adopted during their performance. Practitioners propose variants of this exercise, altering the position of hands and feet; however, there is little research data that describe both relative dynamic and muscular coordination changes throughout those EV. Donkers et al. (8) and An et al. (1) studied the effects of hand positions on elbow-joint load during push-up exercises performed in 6 variants, and they reported significant changes in both static and maximum joint force. Lou et al. (11) and Chou et al. (4) examined those loads at various forearm rotations during push-ups with 2 hands or 1 hand, respectively. Both studies revealed significant changes in magnitude and direction of the joint forces, pointing out that instructions to perform this exercise should be given very carefully, especially when injured or recreational athletes are involved. They also made a clear note of the relevance of push-up exercises with the pattern of falling on 1 or 2 hands.

Other variants of push-ups, such as push-ups with a plus in order to also activate the back muscles, have also been proposed in the literature (7, 10). It has been shown that serratus anterior exhibited different activation levels when lower extremities were positioned on a higher level (10) or on knees (7). Eventually, plyometric and explosive push-ups are used in either training or testing protocols for upper-body power and strength (6, 9, 12, 13).

Although previous studies (1, 8) have examined the clinical effects of altering the position of hands during push-ups on elbow-joint loading, there is lack of scientific evidence that could be used for practical applications, such as constructing a training program. While the popularity of push-ups results partially from their adaptability to different fitness levels, a comprehensive analysis of their requirements regarding the applied forces and the muscular activity is important for the classification of the variants of the exercise into different difficulty levels.

Therefore, the purpose of this study was to record both dynamic behavior and muscular activity during push-up exercises and to investigate their differences during variants of this exercise. It was hypothesized that altering the position of the hands and feet would alter both the relative load and the recruitment pattern of the principle acting muscles.

## Methods

### Experimental Approach to the Problem

Previous research has focused on studying the elbow-joint loading or the muscle activation of the scapular stabilizers during the performance of push-up exercises. They examined variants that altered the orientation of the shoulder joint, elevated hands or feet, provided extra support on knees, increased challenge by using only one hand, extended the exercise by protracting the scapula, or modified the timing events (plyometric push-ups). Our goal was to study only the variants that are sometimes used without knowledge of their potential different challenge. Those variants were formed by altering the position of the hands laterally and in the anterior-posterior direction. We also examined the variant with extra support by placing the knees on the ground. Intending to describe the kinetic profile of each variant, a force plate was used for the collection of the dynamic variables and surface electromyography for the recording of muscle activity (Figure 1). Muscle activity was studied only for the principle muscles for this exercise that are pectoralis major and triceps brachial.

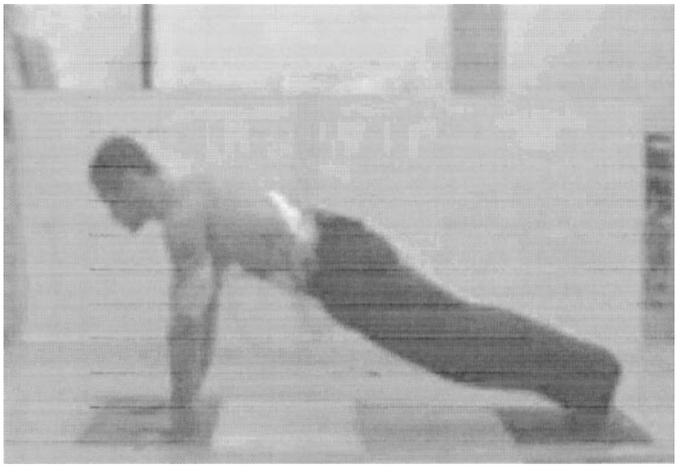

**FIGURE 1.** Experimental set-up.

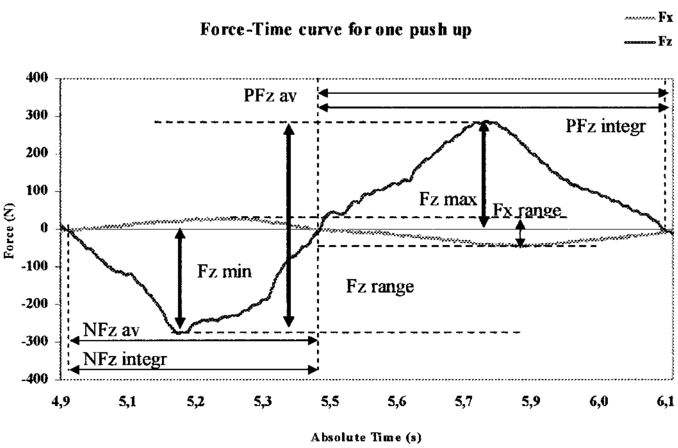


**FIGURE 2.** Ground reaction force variables selected from the force-time curve of 1 push-up.

## Subjects

The sample consisted of 8 men who volunteered to participate. All subjects signed an informed consent in compliance with University policy and were free of upper-extremity injuries or disorders for the last 2 years. They were all healthy men who participated in recreational strengthening programs. During their selection, they were tested in their ability to perform at least 5 consecutive push-ups comfortably and without feeling fatigue.

Their average age was 20.5 (±0.4) years, their height 176.8 (±2.3) cm, and mass 74.4 (±5.1) kg.

## Equipment

Ground reaction forces (GRF) were recorded with a force plate (Type 9281B11, Kistler Instrument, Amherst, NY) with a sampling frequency of 750 Hz and analyzed with Bioware Software (Windows 95, Version 3.0, Kistler Instrument). The force plate provided us with the following data: maximum vertical force ($Fz_{max}$), minimum vertical force ($Fz_{min}$), range of vertical force ($Fz_{range}$), and average vertical force during the descending phase ($NFz_{av}$) and during the ascending phase ($PFz_{av}$), Fz integral during descending ($NFz_{integr}$) and ascending phase ($PFz_{integr}$) as measures of impulse, and finally, range of anteroposterior force ($Fx_{range}$) (Figure 2).

Muscular activity was recorded with surface electromyography. The skin of the subjects was prepared before placing the electrodes by shaving, cleaning the dead skin with a scratching pad, and cleaning with alcohol. Bipolar electrodes were placed on both sides of the body on the pectoralis major (PM) and triceps brachial (T) along the muscle bellies, parallel to the muscle-fiber direction. The electrodes were placed according to the methods described by Cram et al. (5). For the sternal aspect of the PM, the first electrode was placed 2 cm out from the axillary fold and the second 1 cm distal to and in the same longitudinal axis. For the T, the first electrode was placed in half the distance from the olecranon to the acromion, 2 cm from the midline of the arm and the second 1 cm distal to and parallel to the muscle fibers. The electrodes were secured to the skin with tape. The sampling frequency was 1,000 Hz and all raw myoelectric signals were preamplified (gain = 1,000). The appropriateness of electrode placement was confirmed with a manual muscle test for each muscle. After rectification of the signal, the root mean square (RMS) value was calculated for each muscle and EV. The RMS value of the push-up in the normal position was used as the reference and all RMS values at the 5 EV were expressed relative to that.

To screen the experimental procedure and to select the trials for the further analysis, saggital plane motion was video recorded with a speed of 25 frames·$s^{-1}$.

## Testing Procedures

Before the experimental procedure, an adaptation set-up was conducted in order to mark the positions of hands and feet for each one of the 6 EV. At first, the normal posture was adopted in a prone position with the body aligned, feet on the ground, and hands located shoulder-width apart, directly under the shoulder joint. The positions of hands and feet were then marked with tape strips. After the measurement of shoulder width (interacromial distance) and arm-forearm length, strips were placed on the floor marking the positions of hands and feet for the other variants, as follows: 2 marks for the position of hands at the abducted variant, at a distance of 150% of shoulder width; 2 marks for the position of hands at the adducted variant, in a distance of 50% of shoulder width; 2 marks for the position of feet at the anterior variant, in a distance of +30% of arm-forearm length, relative to the marks of the feet in the normal position; 2 marks for the position of feet at the posterior variant, at a distance of −30% of arm-forearm length relative to the marks of the feet in the normal position; finally, 2 marks for the position of knees while subjects readopted the normal position, with their knees touching the floor as well.

The positions of the 6 EV are presented in Figure 3.

Subjects warmed up with static stretching exercises for the upper body and performed 1 trial in each position (EV) to familiarize themselves with the test. For the main procedure, subjects performed 6 sets of push-ups, 1 set for each EV, at random order. Each set consisted of 5 repetitions. Excluding always the first and the fifth of each sequence of trials, the trial that was closer to the described exercise, according to the video recordings, was selected for further analysis.

Before the beginning of each set, subjects were asked to keep their body in a neutral position with their hands positioned on the force plate and the force plate was reset

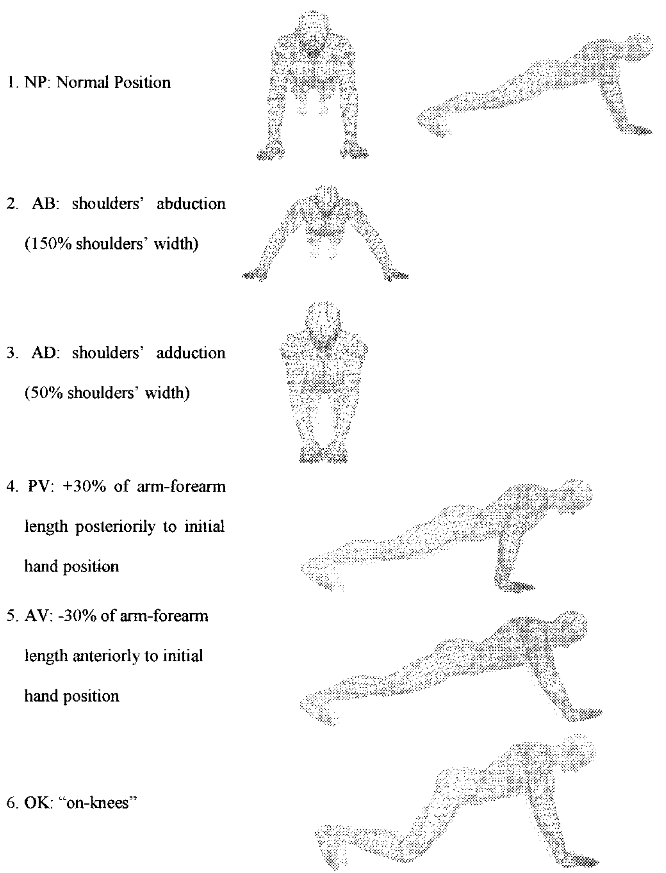


**Figure 3.** The 6 exercise variants (EV) of the experimental procedure.

to 0 to negate the weight of the subject. This weight represented the initial vertical force (initial load: $Fz_{In}$) for each variant. Subjects were instructed to carry out the variants of the push-ups at their own pace. After the completion of each set, subjects were allowed to rest for 3 minutes in order to avoid fatigue.

### Statistical Analyses

Descriptive statistics were calculated for all dynamic and time variables. Univariate analysis of variance (ANOVA) was conducted in order to test the within-subjects effect between repeated measures (EV). In the cases that univariate tests were significant, Tukey's post hoc tests were applied in order to define which EV differed significantly. The significance level was set at 0.05.

The analysis of RMS values was conducted by expressing the RMS of each EV relative to the RMS of the normal posture. Average percentages for all subjects are used for results and discussion.

## Results

The typical pattern of the push-up exercise consists of 2 phases. The flexion phase, where elbows are flexed until the chest approaches the floor, and the extension phase, where elbows are extended until the initial position is achieved. The pattern of the force curve was similar for all subjects. The negative part of the force-time curve represented the descending phase, while the positive the ascending phase.

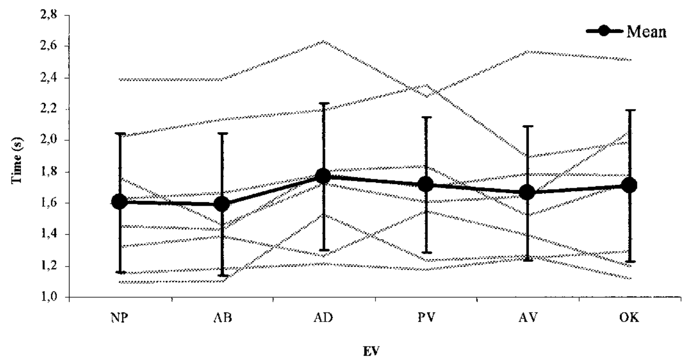


**Figure 4.** Individual and mean (*SD*) duration of 1 push-up performed in all exercise variants (EV).

The duration of 1 push-up ranged between 1.095 and 2.635 seconds, as subjects were instructed to perform the exercise at their own pace. The within-subjects effect of the EV for the total duration was not significant, as there were only slight differences between EV (Figure 4).

Univariate tests for repeated measures showed significant effects ($p \leq 0.05$) for most vertical force variables (Table 1); however, there were no significant differences in the anteroposterior force and time variables.

The initial vertical force ($Fz_{In}$) represented the load at the beginning of each EV. The $Fz_{In}$ was also normalized to each subject's weight ($Fz_{In/BW}$) and expressed the percentage of their body weight that had to be carried by the upper extremities throughout the exercise. The minimum load was carried for the on-knees EV while the maximum for the posterior EV (Figure 5).

Descriptive statistics revealed that, for most subjects, $Fz_{max}$ was higher in the normal position. There was a high variance between subjects regarding the $Fz_{max}$ and $Fz_{min}$ and subsequently the $Fz_{range}$. This variability existed also when those values were normalized to body weight. $Fz_{max}$ and $Fz_{max/BW}$ were higher in the normal position and lower in the anterior variant, while $Fz_{min}$ and $Fz_{min/BW}$ were higher in the posterior variant and lower in the on-knees EV (Table 1).

Descriptive statistics for RMS values of each muscle, normalized as a percentage of RMS at the normal position, were computed for all EV. All muscles showed less activity during the on-knees EV. Muscle activity was also lower when compared with the normal position (100%) during the abducted variant but it was increased during the adducted and anterior EV in almost every muscle (Figure 6).

There was a consistency in the EMG magnitude between muscles for most EV, except for the posterior variant, in which pectoralis major had greater activity than in the normal position, while triceps had less (Figure 6).

## Discussion

Push-up exercises are widely used in strengthening programs for upper-body muscles. The common instructions used by practitioners are that the body should be aligned and hands and feet should provide a stable support base. Although there are suggestions regarding the placement of the hands and programs that introduce the use of progression for either hands or feet during push-ups, there is no clear evidence of the purpose of those variants. In the present study, 6 variants of the push-up exercises

**TABLE 1.** Means and *F* criterion for GRF variables at the 6 EV.

| Variable | *F* | NP | AB | AD | PV | AV | OK |
|---|---|---|---|---|---|---|---|
| Fz In | 60,306* | 489.98 (32.7) | 466.5 (40.7) | 480.0 (42.6) | 538.1 (47.0) | 447.9 (33.3) | 391.1 (45.6) |
| Fz In/BW | 59,753* | 66.4% (2.3) | 63.2% (3.4) | 65.0% (2.6) | 72.9% (3.0) | 60.7% (3.0) | 52.9% (3.5) |
| Fz max | 6,271* | 297.3 (92.0) | 276.0 (82.2) | 228.8 (69.1) | 249.0 (50.5) | 215.9 (44.9) | 252.3 (99.8) |
| Fz max/BW | 6,046* | 40.6% (13.4) | 37.7% (11.9) | 30.3% (9.6) | 34.0% (7.9) | 29.5% (7.0) | 34.6% (14.8) |
| Fz min | 7,173* | −225.3 (81.4) | −223.2 (88.4) | −214.7 (69.9) | −248.5 (79) | −176.6 (59.6) | −165.4 (76.7) |
| Fz min/BW | 7,157* | −31.0% (12.5) | −30.6% (13.2) | −29.4% (10.0) | −34.2% (12.3) | −24.1% (8.4) | −22.7% (11.2) |
| NFz Integr | 10,269* | −66.6 (16.5) | −69.9 (11.8) | −58.7 (16.8) | −73.1 (17.3) | −54.9 (18.2) | −50.2 (22.9) |
| Fz range | 6,824* | 522.7 (165.0) | 499.2 (164.6) | 437.6 (135.1) | 497.5 (123.8) | 392.5 (98.4) | 417.8 (171.8) |

* $p < 0.05$.
Fz In = initial load; Fz In/BW = initial load relative to body weight; Fz max = maximum vertical force; Fz max/BW = maximum vertical force relative to body weight; Fz min = minimum vertical force; Fz min/BW = minimum vertical force relative to body weight; NFz integr = integral of vertical force during descending phase; Fz range = range of vertical force; NP = normal position; AB = abducted variant; AD = adducted variant; PV = posterior variant; AV = anterior variant; OK = on-knees variant.

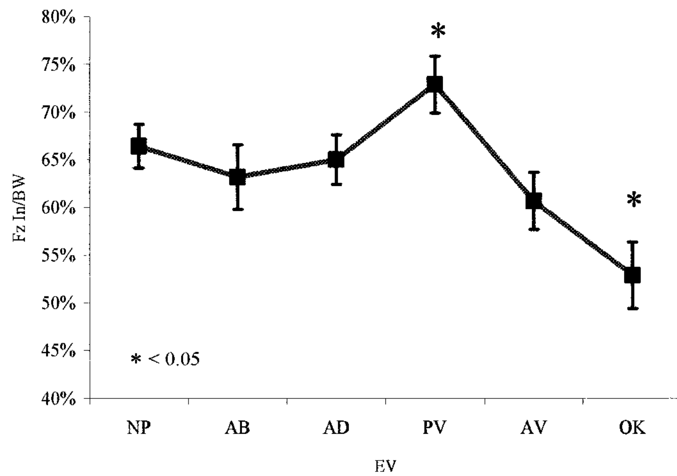


**FIGURE 5.** Mean (*SD*) initial load relative to body weight ($Fz_{In/BW}$) for the 6 exercise variants (EV).

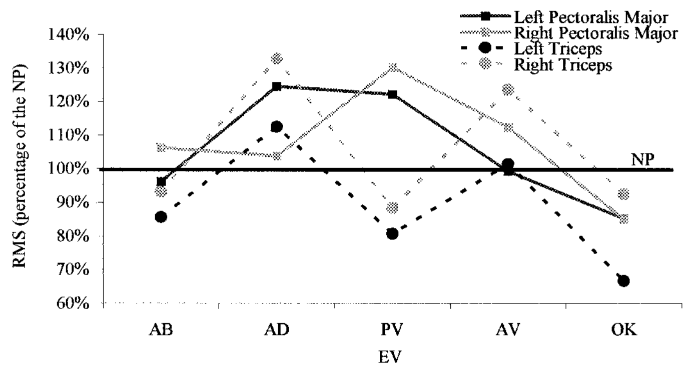


**FIGURE 6.** Root mean square at the 5 exercise variants (EV) expressed relative (%) to muscle activity at the normal position.

were analyzed. Except for the on-knees EV, the rest are commonly used by professional and recreational athletes without segregation. Therefore, the purpose of the present study was to investigate the differences of the dynamic behavior and muscular activity during the performance of variants of push-up exercises.

The general pattern of the exercise, described by the force-time curve, did not seem to change between subjects and between EV. However, between-subjects effects were significant for all time and force variables, and magnitude differences due to EV existed for most vertical-force variables.

The total time for the completion of the exercise varied between subjects, as they were instructed to perform the push-ups at their own pace. The slight changes of the duration between EV for all subjects suggest that the performance pattern, regarding the self-selected pace, remained constant for all conditions (10).

The percentage of body weight that had to be carried by upper extremities throughout the exercise was 66.4 ± 2.3% for the normal position. Hrysomallis and Kidgell (9) found that this load was about 58% of body weight and Donkers et al. (8) and An et al. (1), while studying the pattern of axial forces at the elbow joint, found an average 36.8% of body weight for the initial position. This percentage differed significantly between most EV. There was a slight change in the initial load between the normal position and the abducted or adducted variant, while shoulders remained over the support base. However, Donkers et al. (8) found that the initial axial force at the elbow joint was significantly different for the adducted position. At the posterior EV, initial load was the maximum, indicating that this variant may be quite challenging for untrained subjects. On the contrary, in the on-knees EV, only 52.9% of the body mass was carried, making this variant user friendly even for untrained women and children (7). The different initial loads between EV combined with the similar duration of performances, implies that, in some cases, different amounts of work have to be produced in the same amount of time.

The peak force, which occurred during the extension phase, was, on average, 40.6% of body weight in the normal position, similar to the peak axial force at the elbow joint calculated by Donkers et al. (8), An et al. (1) (45.2% body weight [BW]) and Lou et al (11) (36.2% BW). The maximum force was decreased at the rest EV. Donkers et al. (8) and An et al. (1) found significant differences at the axial forces between normal and abducted (42.7%) and superior (41.9%) positions. Further alterations could lead to even higher force levels, such as performing 1-handed push-ups at a neutral position (65% BW), with internal (47%) or external rotation (57%) (4).

Although, for most subjects, $Fz_{max}$ was higher in the normal position and $Fz_{min}$ in the posterior variant, the magnitude of forces did not show a consistency between the EV, while there was a high variance between subjects. However, the average values revealed that, as for the initial load, the posterior variant exhibited the highest range of force and also demanded the highest impulse ($NFz_{integr}$) during the descending phase. During the ascending phase, $Fz_{max}$ and $PFz_{integr}$ were the highest for the normal position. The average Fz in the ascending phase ($PFz_{av}$) was also higher in the normal position, with a value of 133.2 ($\pm$42.2) N, lower than the value calculated by Wilson et al. (13) (~155 N) and Hrysomallis and Kidgell (9) (~285 N), when push-ups were performed explosively.

It was interesting that, even though the on-knees EV showed the lowest absolute values of initial load, $Fz_{min}$, $Fz_{min/BW}$, $NFz_{integr}$, and $Fz_{range}$, this was not true for the respective values of the ascending phase. We can speculate that the extra support on the knees was very helpful during the descending phase but its contribution was much less during the ascending phase. The above results provide clear implications regarding the importance of both phases when performing push-up exercises. The role of both phases should be examined separately when push-ups are performed eccentrically or explosively (9, 13).

The anterior-posterior forces did not exhibit any significant differences between EV. On the contrary, Donkers et al. (8) and An et al. (1) found that significant differences existed in the elbow-joint force between the normal and the abducted positions (6.4% BW). Anterior-posterior forces are probably more important when introducing variants of internal or external rotation of the hands. Lou et al. (11) concluded that the internally rotated position had the largest posterior shear forces and should be avoided to protect the elbow joint from injuries.

The mediolateral force revealed no clear pattern between subjects (8) and, for that reason, data were not statistically analyzed for that variable.

Although the analysis of forces provided us with important information regarding the demands of the push-up exercises when performed in different positions, a detailed kinematic analysis could provide us also with clinical implications. Donkers et al. (8) found that the peak torque represented more than 50% of the maximum strength of the triceps, while, with adjustments of position the hands, this torque could be increased to 70%. The pattern of falling is similar to that of push-ups and observing the variation of the exerted load assists in understanding the risks of injury (4, 11, 12).

When analyzing the EMG results, we avoided any attempt to compare subjects and the lateral sides of the body because of the potential error resulting from the electrode placements. The present analysis aimed at comparing the total muscle activity between EV and the relative contribution of the principle muscles; that rendered EMG normalization by maximum voluntary contraction unnecessary. Push-ups include eccentric and concentric contractions, where different levels of muscle tension are developed. While we analyzed this dynamic activity from a functional perspective, without any clinical implications, information of the muscular activity according to the type of muscle contractions was needed (2, 10). Therefore, the normal position, which required maximum muscle activation, may be more representative of a muscle's true maximum voluntary contraction than a traditional manual muscle test and, for that reason, it was used as the reference data column. In this sense, EMG results could be useful for strength-training programs. The average EMG amplitude represents the muscular activity within a force phase and may be important for endurance training. Exercises with larger average amplitudes may offer greater muscular challenges and require greater physiologic efforts (7).

It turned out that the on-knees EV was the least demanding, regarding the muscle activity. Although the relationship between EMG activity and force is multifactorial, investigators have generally assumed that force increases, whether linearly or nonlinearly, with EMG (7). For that reason, the lower muscle activity in the on-knees EV could be explained by the fact that, in this posture, the initial load was lower. Blackard et al. (3) have stated the significance of load when classifying an activity. They proved that there is no difference between exercises of equivalent loads regarding normalized EMG for PM and T. They supported the notion that the external load, the articulations, and the range of motion (ROM) involved in the movement should all be defined. In our case, we dealt with EV with the same articulations but the biomechanical actions and loading were different because both ROM and initial load were altered by positional changes.

The only EV that exhibited totally different patterns in muscle recruitment was the posterior variant, where pectoralis major was more active than in the normal position, while triceps were less active, pointing out that this variant can be used mainly for strengthening programs for the pectoralis major. Our initial hypothesis indicated that position might cause some muscles to be more or less active (2). When modifying the direction of force application, changes in the recruitment order of the motor units of the muscles may appear. A possible explanation, given by Wilson et al. (13), is that differences in posture involve changes in the neural input to the muscles. Although this is a potential explanation, the fact that push-ups are multiple-articulation exercises makes formulation of conclusions difficult because of the amount of muscular coordination required.

The observed differences in the dynamic and muscular profiles of push-ups when performed with different positions imply the careful utilization of each EV when anticipating specific results. Posture is important in training because its benefits are transferred to performance and the selection of specific techniques influences the achievement of the prospective goal (2, 13).

## PRACTICAL APPLICATIONS

Push-up exercises are widely used in strengthening programs for competitive and recreational athletes. Although basic instructions include body's posture, usually no accurate descriptions exist regarding the placement of hands and feet. The present study found that a clear distinguishment should exist between the different postures, as significant differences existed in force variables and muscular activity. Practitioners can alter the initial load that subjects have to carry by altering the position of the hands and by supplying extra support, like when standing on knees. The importance of both phases (ascending and descending) should be reported, as force variables showed different behaviors during those phases. Posture is also essential to muscle activity, altering the ratio of recruitment of different muscles or the muscle-activity demands. Practitioners should pay attention to their anticipated results regarding specific muscles.

Therefore, because parameters, such as duration, range of motion, position, posture, and relative contribution of phases, are crucial when push-ups are performed, further research is needed in this area. In conclusion, practitioners should be careful when giving instructions and describing push-ups; otherwise, their prospective goals may not be achieved as initially planned.

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