Journal of Athletic Training 2015;50(11):1126–1132
doi: 10.4085/1062-6050-50.9.09

www.natajournals.org

original research

Selective Activation of Shoulder, Trunk, and Arm Muscles: A Comparative Analysis of Different Push-Up Variants

Giuseppe Marcolin, PhD*; Nicola Petrone, PhD†; Tatiana Moro, MSc*; Giuseppe Battaglia, PhD‡; Antonino Bianco, PhD‡; Antonio Paoli, MD*

*Department of Biomedical Sciences and †Department of Industrial Engineering, University of Padova, Italy; ‡Sport and Exercise Sciences Research Unit, University of Palermo, Italy

Context: The push-up is a widely used exercise for upper limb strengthening that can be performed with many variants. A comprehensive analysis of muscle activation during the ascendant phase (AP) and descendant phase (DP) in different variants could be useful for trainers and rehabilitators.

Objective: To obtain information on the effect of different push-up variants on the electromyography (EMG) of a large sample of upper limb muscles and to investigate the role of the trunk and abdomen muscles during the AP and DP.

Design: Cross-sectional study.

Setting: University laboratory.

Patients or Other Participants: Eight healthy, young volunteers without a history of upper extremity or spine injury.

Intervention(s): Participants performed a set of 10 repetitions for each push-up variant: standard, wide, narrow, forward (FP), and backward (BP). Surface EMG of 12 selected muscles and kinematics data were synchronously recorded to describe the AP and DP.

Main Outcome Measure(s): Mean EMG activity of the following muscles was analyzed: serratus anterior, deltoideus anterior, erector spinae, latissimus dorsi, rectus abdominis, triceps brachii caput longus, triceps brachii caput lateralis, obliquus externus abdominis, pectoralis major sternal head, pectoralis major clavicular head, trapezius transversalis, and biceps brachii.

Results: The triceps brachii and pectoralis major exhibited greater activation during the narrow-base variant. The highest activation of abdomen and back muscles was recorded for the FP and BP variants. The DP demonstrated the least electrical activity across all muscles, with less marked differences for the abdominal and erector spinae muscles because of their role as stabilizers.

Conclusions: Based on these findings, we suggest the narrow-base variant to emphasize triceps and pectoralis activity and the BP variant for total upper body strength conditioning. The FP and BP variants should be implemented carefully in participants with low back pain because of the greater activation of abdominal and back muscles.

Key Words: fitness, training, kinesiology, rehabilitation

Key Points

- During the push-up exercise, hand position can influence the electromyographic activity of different muscles.
- A narrow hand position (hands together with the right thumb and forefinger touching the left thumb and forefinger below the center of the sternum) elicited greater activation for both the triceps brachii and pectoralis major muscles.
- Changing the position of the hands forward or backward can increase the electromyographic activity of the abdominal and back muscles.

The push-up is a very popular closed kinetic chain exercise used in both rehabilitation and strength programs. This exercise is popular because the push-up can be performed without any additional tools and the intensity can be altered with several variations, thus making it suitable for almost every level of fitness. Surface electromyography (EMG) and kinetic analysis are the techniques used most often to investigate the push-up and its variants. Cogley et al[1] examined the muscle activation of the triceps brachii and pectoralis major in the push-up, showing that the narrow-base hand position elicited greater activation of both muscles compared with the wide-base hand position. Gouvali and Boudolos[2] analyzed dynamic behavior and muscular activity (triceps brachii and pectoralis major) in 6 push-up variants performed with the hands on a force plate. They reported that posture was important in changing muscle recruitment ratios and support of the initial load. The percentage of body mass supported by the upper extremities during the traditional and the knees-down push-up also was investigated by recording the vertical component of the ground reaction force during 2 characteristic static positions: up and down. The traditional push-up required support of a larger percentage of body mass than the modified push-up, and the down static position required more support of body mass than the up position.[3] Garcia-Masso et al[4] described vertical reaction force and muscle activation during different plyometric push-ups, providing data that contributed to a more correct and effective prescription. Previous authors[5] also focused on the effect that unstable surfaces could have on muscle activity. They described the influence of hand suspension on the abdominal and trunk muscles and quantified the resultant intervertebral joint loading.[5] Both trunk muscle activity and intervertebral joint compressive loading increased with the standard push-up (SP), creating a potential risk of overloading the low back tissues in participants who cannot sustain such loads.

Similarly, Freeman et al[6] showed that more dynamic push-ups, such as the ballistic version with hand movements, required more muscle activation and produced a greater load on the spine, whereas placing labile balls under the hands resulted in only a modest increase in spine load. The introduction of unstable surfaces under the hands does not seem to be an effective solution to increase either muscular strength or endurance in well-trained, healthy participants.[7] Again, with the aim of increasing the activation of selected muscles in both training and rehabilitation protocols, specific tools were developed and commercially distributed.[8–10] Previous researchers[11] showed that the use of special handgrips did not enhance muscular recruitment with respect to push-ups performed with the hands on the floor. Serratus anterior and middle and lower trapezius activity were investigated using a special rehabilitation device. The device can be an alternative to the SP if the goal of the rehabilitation protocol is to stimulate the serratus anterior and the patient lacks the upper body strength to perform the SP on the floor.[12]

Therefore, the aim of our study was to investigate the effect of 5 push-up variants on activation of a larger sample of muscles that involved not only the arms and shoulders but also the abdomen and trunk. To our knowledge, only 1 group[13] investigated the 2 distinct phases of the push-up (ascending and descending) but in terms of type of exercise, number of repetitions, and duration of each repetition, the protocol was more specific for rehabilitation than for training purposes. We also wanted to analyze more muscles to gain more information about the development of strength and rehabilitation protocols focused on the activation of specific muscles. The second aim of the study was to analyze the ascendant phase (AP) and descendant phase (DP), concentrating on the EMG activity of the selected muscles during these 2 conditions. We hypothesized that different push-up variants might elicit different EMG magnitudes. We expected a lower level of muscle activation during the DP except for the abdominal and trunk muscles because of their stabilizing role.[9]

METHODS

Participants and Setting

Eight students of the Exercise Science Faculty of the University of Padova were enrolled in the study. All participants were physically active in different sports, had at least 1 year of experience in resistance training, and were accustomed to the push-up exercise. At the time of the study, participants did not present with any injuries of the wrists, elbows, or shoulders. An informed consent that described all testing procedures was read and signed by each participant before starting the experimental procedures. The study was reviewed and approved by the local ethics committee.

Testing Procedures

We used a 6-camera infrared stereophotogrammetric system operating at 60 Hz (model SMART Classic; BTS Bioengineering, Garbagnate Milanese, Italy) to collect kinematic data from passive reflective spherical markers placed bilaterally on specific anatomical landmarks to create a full-body model. On the model, markers were secured with medical double-sided adhesive tape on the head (helmet with 3 markers applied), trunk (acromions and spinous process of seventh cervical vertebra), arms (lateral and medial wrist epicondyle, ulnar and radial styloid process), hand (top of the third metacarpal bone), pelvis (anterior-superior iliac spine and posterior-superior iliac spine), thigh (great trochanter and lateral condyle), shank (fibular head), and foot (calcaneus and head of the fifth metatarsal). Surface EMG signals of 12 muscles on the right side of each participant were synchronously recorded at 1 kHz by means of a PDA PocketEMG (BTS Bioengineering). Device resolution was 16 bits, weight was 300 g, and dimensions were 145 × 95 × 20 mm. Muscles investigated were the serratus anterior, deltoideus anterior, erector spinae (ES), latissimus dorsi, rectus abdominis (RA), triceps brachii caput longus, triceps brachii caput lateralis, obliquus externus abdominis (OEA), pectoralis major sternal head, pectoralis major clavicular head, trapezius transversalis, and biceps brachii. Bipolar surface electrodes were placed on the muscle belly along the direction of the muscle fibers.[14] The distance between electrodes was 25 mm, equal to the diameter of a single electrode.

Before electrode placement, we shaved the skin and cleaned it with alcohol. The participant was asked to make selected movements for each muscle to verify the correct placement of the pregelled sensors and to avoid EMG signal saturation. Each participant received the following guidelines regarding the execution of the 5 push-up variants.

The SP was performed with hands under the shoulders at a distance corresponding to acromion width. In the wide-base push-up (WP), the distance between hands was double that in the SP. In the narrow-base push-up (NP), the hands stayed together with the right thumb and forefinger touching the left thumb and forefinger below the center of the sternum. In the last 2 variants, the hands remained at acromion width but 20 cm in front (forward push-up [FP]) of or 20 cm behind (backward push-up [BP]) the acromions. A rigid posture with trunk and legs aligned was required for all the variants; the participants had to look ahead during the exercise. Positions of the hands and feet were measured and marked using pieces of commercial tape; foot position remained the same for the 5 variants performed. Each set of push-ups consisted of 10 repetitions. The duration of a single repetition was set to 2.5 seconds using a metronome and measured accurately using kinematic data. For each participant, 5 minutes of practice preceded the tests. Push-up variants were performed by each participant in random order. A rest time of 3 minutes occurred between push-up variants.

Data Analysis

We identified the 2 phases of each push-up repetition by looking at the displacement of the virtual marker and calculated the mean of the 2 markers placed on the acromions. In particular, the DP started when the virtual marker reached the highest vertical value and ended when it showed the lowest vertical value. Conversely, the AP was measured from the lowest to the highest vertical position of the virtual marker. The EMG raw signals were first rectified around the mean value, then integrated with a mobile window of 200 milliseconds, and finally smoothed with a fourth-order Butterworth low-pass filter with a cutoff frequency of 5 Hz. As reported in our previous study,[15] the first and last repetitions of the 5 push-up variants were not considered in the analysis because kinematic evaluation showed these repetitions were inconsistent.

The mean value of the processed EMG signals was computed for each of the 8 repetitions, taking into consideration the DP, the AP, and the motion as a whole. Lastly, we calculated the group average across the 8 participants for each variant and each phase.

Statistical Analysis

One-way analysis of variance (ANOVA) for repeated measurements was used to analyze within-groups differences among muscles after the 5 push-up variants. A paired *t* test was carried out for each muscle to analyze EMG amplitude differences between the AP and DP in the 5 distinct hand positions. The significant *P* level was set at .05 and for the ANOVA, if appropriate, a Tukey post hoc test was conducted. Gaussian distribution of data was verified using the D'Agostino-Pearson omnibus normality test. Data analysis was performed using the software package GraphPadPrism (version 5.00 for Windows; GraphPad Software, San Diego, CA).

RESULTS

The comparison between the AP and DP showed differences for all the muscles and all the variants. The mean activity of each muscle during the whole task and then during the AP and DP is shown for each push-up variant in Figure 1. The results of the Tukey post hoc comparisons among the 5 variants are given in the Table. For each participant, the average time among the 8 repetitions was computed; the mean among participants is reported as a single data point.

Serratus Anterior

The different hand positions resulted in differences in EMG activity ($P < .0001$, $F = 72.83$). The Tukey post hoc test showed no differences between the SP and NP, SP and BP, WP and FP, or NP and BP variants. The comparison of the AP and DP was significant for the SP ($P < .0001$, $t = 32.65$), WP ($P < .0001$, $t = 25.99$), NP ($P < .0001$, $t = 44.08$), FP ($P < .0001$, $t = 25.52$), and BP ($P < .0001$, $t = 19.99$).

Deltoideus Anterior

The EMG activity showed significant differences ($P < .0001$, $F = 95.74$) even when the multiple-comparisons test demonstrated no changes for the SP versus WP, SP versus NP, and WP versus NP variants. The paired *t* test to compare AP and DP was significant for SP ($P < .0001$, $t = 11.37$), WP ($P < .0001$, $t = 15.50$), NP ($P < .0001$, $t = 21.68$), FP ($P < .0001$, $t = 15.07$), and BP ($P < .0001$, $t = 9.963$).

Erector Spinae

The different positions were associated with differences in EMG activity ($P < .0001$, $F = 161.0$). The Tukey post hoc test revealed differences only between the SP and BP, WP and BP, NP and BP, and FP and BP. The comparison of the 2 phases was significant for the SP ($P < .0001$, $t = 11.14$), WP ($P = .0002$, $t = 6.947$), NP ($P = .002$, $t = 4.803$), FP ($P = .0425$, $t = 2.475$), and BP ($P = .0168$, $t = 3.123$).

Latissimus Dorsi

The different hand positions were characterized by significant differences in EMG activity ($P < .0001$, $F = 71.57$). When we calculated the Tukey multiple-comparisons test, only the differences for the SP versus WP and NP versus FP were not significant. The comparison of the AP and DP was significant in the SP ($P < .0001$, $t = 24.77$), WP ($P < .0001$, $t = 24.56$), NP ($P < .0001$, $t = 23.12$), FP ($P < .0001$, $t = 27.47$), and BP ($P = .0019$, $t = 4.812$).

Rectus Abdominis

The different hand positions resulted in differences in EMG mean activity ($P < .0001$, $F = 225.3$). The Tukey post hoc test showed no differences between the WP and NP or between the WP and BP. The paired *t* test to compare DP and AP was significant for the SP ($P < .0001$, $t = 12.43$), WP ($P < .0001$, $t = 9.626$), NP ($P < .0001$, $t = 11.72$), FP ($P < .0001$, $t = 9.962$), and BP ($P = .0011$, $t = 5.353$).

Triceps Brachii Caput Longus

The EMG activity demonstrated differences ($P < .0001$, $F = 300.3$) and the Tukey post hoc test was significant for all comparisons. The paired *t* test to compare the AP and DP was significant for the SP ($P < .0001$, $t = 11.99$), WP ($P < .0001$, $t = 9.702$), NP ($P < .0001$, $t = 13.68$), FP ($P < .0001$, $t = 29.34$), and BP ($P < .0001$, $t = 8.914$).

Triceps Brachii Caput Lateralis

The different hand positions were characterized by differences in EMG mean activity ($P < .0001$, $F = 159.7$); the multiple-comparisons test showed no differences only between the SP and BP. The comparison of DP and AP was significant in the SP ($P < .0001$, $t = 20.21$), WP ($P < .0001$, $t = 20.25$), NP ($P < .0001$, $t = 26.32$), FP ($P < .0001$, $t = 17.66$), and BP ($P < .0001$, $t = 15.63$).

Obliquus Externus Abdominis

The different hand positions resulted in differences in EMG mean activity ($P < .0001$, $F = 233.7$). The multiple-comparisons test was not significant only for the SP versus BP. The AP and DP differed in the SP ($P < .0001$, $t = 9.722$), WP ($P = .0049$, $t = 4.049$), NP ($P < .0001$, $t = 10.16$), FP ($P = .0048$, $t = 4.055$), and BP ($P = .0006$, $t = 5.889$).

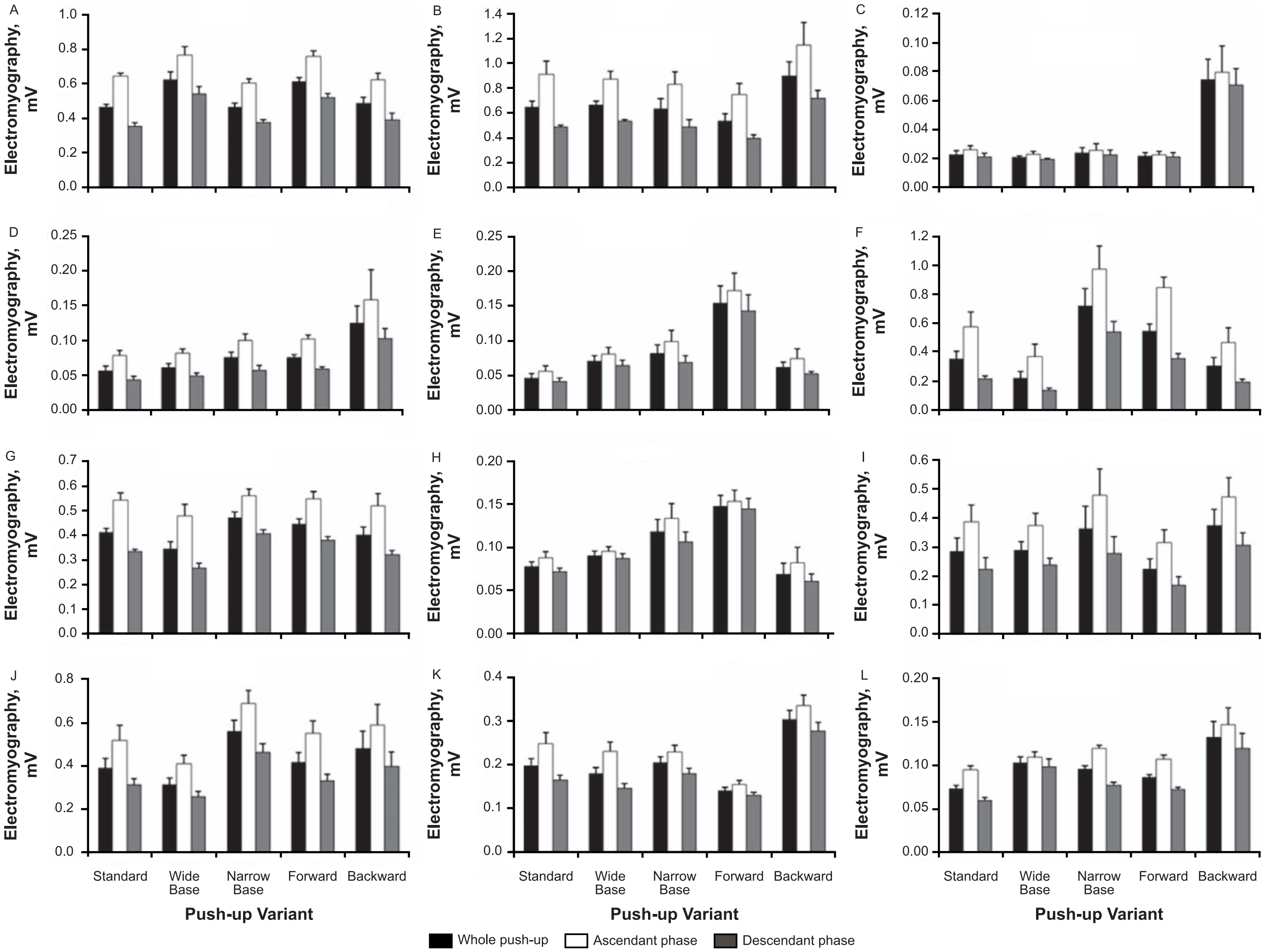

Figure 1. Overall mean electromyographic activity of each muscle for each of the 5 push-up variants. Data are expressed as mean ± SD. A, Serratus anterior. B, Deltoideus anterior. C, Erector spinae. D, Latissimus dorsi. E, Rectus abdominis. F, Triceps brachii caput longus. G, Triceps brachii caput lateralis. H, Obliquus externus abdominis. I, Pectoralis major sternal head. J, Pectoralis major clavicular head. K, Trapezius transversalis. L, Biceps brachii.

Table. Electromyographic Activity in Push-Up Comparisons: Results of the Tukey Post Hoc Multiple-Comparisons Tests

	Push-Up Comparison									
	Standard Versus				Wide Versus			Narrow Versus		Forward Versus
Muscle	Wide	Narrow	Forward	Backward	Narrow	Forward	Backward	Forward	Backward	Backward
Serratus anterior	a		a		a		a	a		a
Deltoideus anterior			a	a		a	a	a	a	a
Erector spinae				a			a		a	a
Latissimus dorsi		a	a	a	b	b	a		a	a
Rectus abdominis	a	a	a	a		a		a	a	a
Triceps brachii caput longus	a	a	a	b	a	a	a	a	a	a
Triceps brachii caput lateralis	a	a	a		a	a	a	a	a	a
Obliquus externus abdominis	a	a	a		a	a	a	a	a	a
Pectoralis major sternal head		a	a	a	a	a	a	a		a
Pectoralis major clavicular head	a	a		a	a	a	a	a	a	a
Trapezius transversalis	a		a	a	a	a	a	a	a	a
Biceps brachii	a	a	b	a		a	a		a	a

[a] Significant difference ($P < .01$).
[b] Significant difference ($P < .05$).

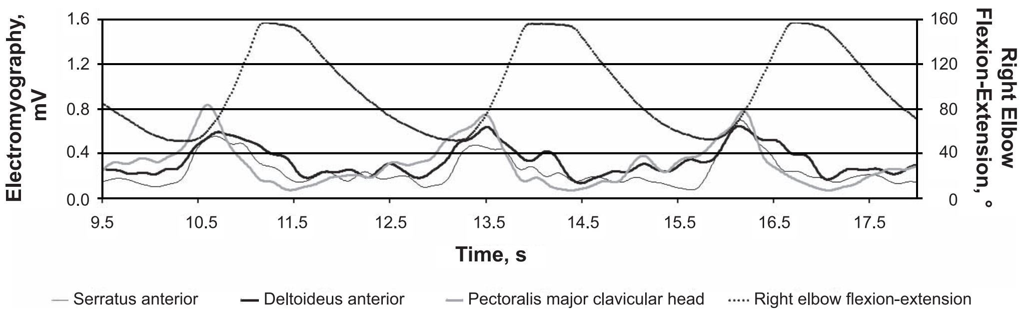

Figure 2. Electromyographic activity of the serratus anterior, deltoideus anterior, and pectoralis major clavicular head with respect to right elbow flexion-extension. Example shows 3 complete repetitions.

Pectoralis Major Sternal Head

Differences in EMG mean activity were evident with the different hand positions ($P < .0001$, $F = 77.12$). The Tukey multiple-comparisons test was not significant only for the SP versus WP and the NP versus BP. The AP and DP differed in the SP ($P < .0001$, $t = 15.00$), WP ($P < .0001$, $t = 15.68$), NP ($P < .0001$, $t = 17.41$), FP ($P < .0001$, $t = 22.66$), and BP ($P < .0001$, $t = 17.44$).

Pectoralis Major Clavicular Head

Using the 1-way ANOVA for repeated measurements, we found differences ($P < .0001$, $F = 180.9$). The Tukey post hoc test demonstrated no differences only between the SP and FP. The paired t test was significant in the SP ($P < .0001$, $t = 13.28$), WP ($P < .0001$, $t = 19.18$), NP ($P < .0001$, $t = 24.50$), FP ($P < .0001$, $t = 18.17$), and BP ($P < .0001$, $t = 16.49$).

Trapezius Transversalis

Different hand positions were associated with different levels of EMG activity ($P < .0001$, $F = 517.0$). The Tukey multiple-comparisons test revealed that only the comparison between the SP and NP was not significant. The AP and DP were different in the SP ($P < .0001$, $t = 12.83$), WP ($P < .0001$, $t = 16.29$), NP ($P < .0001$, $t = 12.12$), FP ($P = .0003$, $t = 6.716$), and BP ($P < .0001$, $t = 9.723$).

Biceps Brachii

The 1-way ANOVA for repeated measurements revealed differences ($P < .0001$, $F = 73.54$). The Tukey post hoc test showed no differences only between the WP and NP and between the NP and FP. The paired t test was significant for the SP ($P < .0001$, $t = 23.89$), WP ($P = .0176$, $t = 3.090$), NP ($P < .0001$, $t = 46.34$), FP ($P < .0001$, $t = 24.30$), and BP ($P < .0001$, $t = 10.77$).

DISCUSSION

Our results showed how push-up variants influenced the EMG activity of specific muscles. Considering that at a constant tension, the electrical activity increased linearly with shortening velocity,[16] the choice of a preselected cadence supplied consistency to our findings.

Kinematic data synchronization with EMG signals allowed us to better understand muscle activity during the whole exercise. The most active muscles were the pectoralis major, triceps brachii, serratus anterior, and deltoideus anterior. We found a typical repeated activation pattern with a higher EMG level as the AP began and a lower level immediately after the DP began. The EMG activity and right elbow angle of a participant exemplify this pattern (Figure 2). These data support the findings of Suprak et al,[3] who recorded a greater percentage of body mass supported by the hands in the down position versus the up position.

Our participants performed dynamic push-ups, so the greater EMG activity reflected not only different moment arms between the support surface contact point and the hands but also the fact that the body must accelerate in this initial phase against gravity and the inertia of the body itself, which is descending.[3]

The analysis of a large sample of muscle and hand-position variants resulted in useful information on the effort required for each of the push-up variants. If the aim of the athlete is to focus on the pectoralis and triceps muscles, the NB is preferred. However, if total upper body strength and conditioning is the goal, the BP variant is preferred because it challenges 7 of the 12 muscles. The BP and FP variants should be used carefully in athletes or patients with low back pain to avoid the possibility of spine overload from a high activation of the abdominal and back muscles. In fact, considering previous investigations,[5,6] the high activation of the ES and latissimus dorsi in the BP variant and of the RA and OEA in the FP variant suggests an increase in intervertebral joint compressive forces.

Our results partially confirmed the data of Cogley et al.[1] In fact, the NP variant elicited greater activation for both the triceps brachii and pectoralis major with respect to WP, but we also detected differences for these muscles in comparison with the SP variant, except for the sternal head of the pectoralis major. These slight differences might be attributable to different methods. Indeed, we evaluated 8 repetitions, excluding the first and the last, whereas Cogley et al[1] assessed a single repetition; we also selected a faster cadence. We must consider our study as a pilot intervention that needs to be confirmed after this first encouraging investigation. It is important to highlight that our data agree with the results of Gouvali and Boudolos[2] showing greater activation of both the triceps brachii and pectoralis major with the NP push-up than the SP and increased activation of the pectoralis major and decreased activation of the triceps brachii when comparing the SP and BP.[2] In contrast, our triceps brachii data are in accord with those of Youdas et al[11] comparing the SP and WP variants, although the

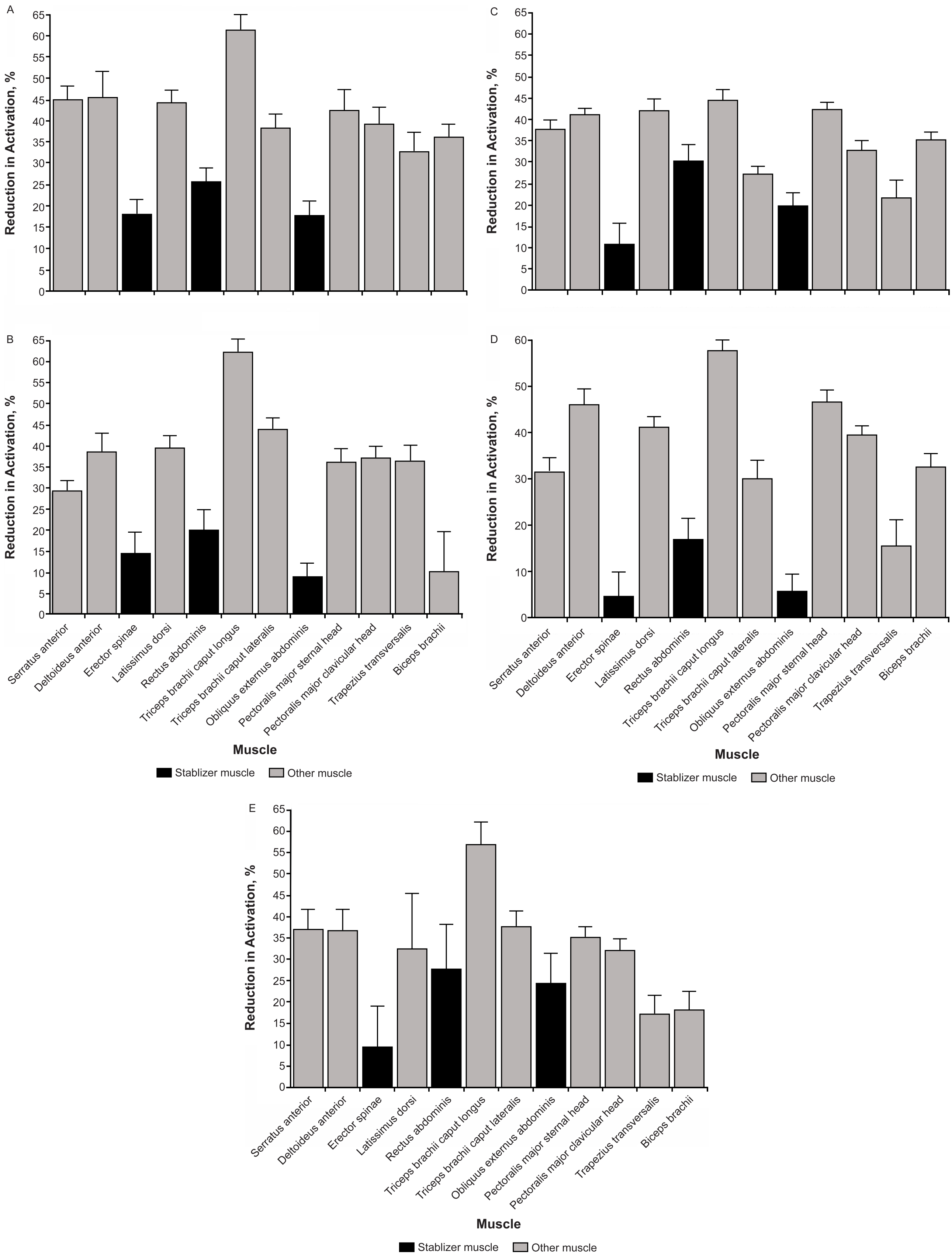

Figure 3. Electromyographic percentage of variation between the ascendant and the descendant phases, with respect to the highest (ascendant). Black columns represent stabilizer muscles with a small difference between the 2 phases. A, Standard push-up. B, Wide push-up. C, Narrow push-up. D, Forward push-up. E, Backward push-up.

pectoralis major activation was not influenced by a change in hand position, which was not in accord with our study.

Differences among data may be attributable to the different number of repetitions, the different cadences of execution, and the choice to analyze mean rather than peak EMG.[11] Our methodologic choice had the aim of reproducing as closely as possible the number of repetitions usually used during rehabilitation.

The second hypothesis tested in this study was that all muscles except the RA, ES, and OEA would show a lower level of activity during the DP because of their stabilizing roles. This hypothesis was not confirmed; differences were also apparent for these stabilizer muscles when the 2 phases were compared. However, if we consider the EMG differences in percentages with respect to the highest one (AP), the ES, RA, and OEA muscles showed smaller differences than the serratus anterior, deltoideus anterior, triceps brachii, and pectoralis major, the most involved muscles during the push-up (Figure 3). This is particularly evident in the FP and WP variants and reflects the prime contributions of these muscles in preserving the correct posture during execution of the task, aligning and stabilizing the trunk and legs.

REFERENCES

1. Cogley RM, Archambault TA, Fibeger JF, Koverman MM, Youdas JW, Hollman JH. Comparison of muscle activation using various hand positions during the push-up exercise. *J Strength Cond Res*. 2005;19(3):628–633.
2. Gouvali MK, Boudolos K. Dynamic and electromyographical analysis in variants of push-up exercise. *J Strength Cond Res*. 2005;19(1):146–151.
3. Suprak DN, Dawes J, Stephenson MD. The effect of position on the percentage of body mass supported during traditional and modified push-up variants. *J Strength Cond Res*. 2011;25(2):497–503.
4. Garcia-Masso X, Colado JC, Gonzalez LM, et al. Myoelectric activation and kinetics of different plyometric push-up exercises. *J Strength Cond Res*. 2011;25(7):2040–2047.
5. Beach TA, Howarth SJ, Callaghan JP. Muscular contribution to low-back loading and stiffness during standard and suspended push-ups. *Hum Mov Sci*. 2008;27(3):457–472.
6. Freeman S, Karpowicz A, Gray J, McGill S. Quantifying muscle patterns and spine load during various forms of the push-up. *Med Sci Sports Exerc*. 2006;38(3):570–577.
7. Chulvi-Medrano I, Martínez-Ballester E, Masiá-Tortosa L. Comparison of the effects of an eight-week push-up program using stable versus unstable surfaces. *Int J Sports Phys Ther*. 2012;7(6):586–594.
8. Lehman GJ, MacMillan B, MacIntyre I, Chivers M, Fluter M. Shoulder muscle EMG activity during push up variations on and off a Swiss ball. *Dyn Med*. 2006;5:7.
9. Lehman GJ, Gilas D, Patel U. An unstable support surface does not increase scapulothoracic stabilizing muscle activity during push up and push up plus exercises. *Man Ther*. 2008;13(6):500–506.
10. Goodman CA, Pearce AJ, Nicholes CJ, Gatt BM, Fairweather IH. No difference in 1RM strength and muscle activation during the barbell chest press on a stable and unstable surface. *J Strength Cond Res*. 2008;22(1):88–94.
11. Youdas JW, Budach BD, Ellerbusch JV, Stucky CM, Wait KR, Hollman JH. Comparison of muscle-activation patterns during the conventional push-up and perfect pushup exercises. *J Strength Cond Res*. 2010;24(12):3352–3362.
12. Tucker WS, Campbell BM, Swartz EE, Armstrong CW. Electromyography of 3 scapular muscles: a comparative analysis of the cuff link device and a standard push-up. *J Athl Train*. 2008;43(5):464–469.
13. Sandhu JS, Mahajan S, Shenoy S. An electromyographic analysis of shoulder muscle activation during push-up variations on stable and labile surfaces. *Int J Shoulder Surg*. 2008;2(2):30–35.
14. Hermens HJ, Freriks B, Disselhorst-Klug C, Rau G. Development of recommendations for SEMG sensors and sensor placement procedures. *J Electromyogr Kinesiol*. 2000;10(5):361–374.
15. Paoli A, Marcolin G, Petrone N. The effect of stance width on the electromyographical activity of eight superficial thigh muscles during back squat with different bar loads. *J Strength Cond Res*. 2009;23(1):246–250.
16. Bigland B, Lippold OC. The relation between force, velocity and integrated electrical activity in human muscles. *J Physiol*. 1954;123(1):214–224.

Address correspondence to Antonio Paoli, MD, Department of Biomedical Sciences, University of Padova, via Marzolo 3, Padova, 35131 Italy. Address e-mail to antonio.paoli@unipd.it.