

Original Research

Upper Body Muscular Activation during Variations of Push-Ups in Healthy Men

CAROLINE C. ALLEN*, KATIE A. DEAN*, ALAN P. JUNG‡, and JOHN K. PETRELLA‡

Department of Kinesiology and Nutrition Science, Samford University, Birmingham, Alabama, USA

*Denotes undergraduate student author, ‡Denotes professional author

ABSTRACT

International Journal of Exercise Science 6(4) : 278-288, 2013. The purpose of this study was to assess neural activity for upper body musculature in college-age men during repetitions of a conventional pushup or a Perfect Pushup™. Eighteen healthy men (21.6±1 yr, 182.5±7 cm, 87.4±15 kg) completed five repetitions of a conventional pushup and Perfect Pushup™ while using a wide hand base of support for the upper body. Body position, hand placement, and cadence of the pushup were standardized. Root mean square electromyography (RMS-EMG, mV/Sec) was collected for the triceps brachii (TB), pectoralis major (PM), serratus anterior (SA), and posterior deltoid (PD) during all repetitions. RMS-EMG values were normalized to a maximal voluntary isometric contraction in the pushup position (%MVIC_{PU}). For each muscle, %MVIC_{PU} for repetitions 1, 3, and 5 were analyzed for differences due to type of push-up. No differences in %MVIC_{PU} due to type of push-up for the TB ($p=0.079$) or the SA ($p=0.45$) were detected. The Perfect Pushup™ increased %MVIC_{PU} compared to the conventional pushup (44%, $p<0.05$). Additionally, the Perfect Pushup™ increased %MVIC_{PU} by the third repetition ($p<0.05$) while the conventional pushup did not until the 5th repetition. The conventional pushup activated more PD (76%, $p<0.05$). The type of push-up that requires the greatest neural activity for a given number of repetitions should result in improved adaptations. The Perfect Pushup™ was superior for activating the pectoralis major while individuals would elicit more neural activation in the posterior deltoid by conventional push-ups. Trainers and rehabilitation specialists should consider these data when attempting to train or isolate upper body skeletal muscles using a push-up movement.

KEY WORDS: Perfect Pushup, electromyography, resistance exercise

INTRODUCTION

Conventional push-ups are a widely accepted means of assessing and improving upper body strength and endurance (4) due to the simple technique and the requirement of very little equipment (15). In recent years, a rotating handgrip device has been developed (Perfect Pushup™) which the manufacturer claims will result in greater muscular responses and

adaptations in comparison to conventional push-ups (8). It is suggested that this increased adaptation occurs by taking advantage of a rotating movement in the arms during the ascending and descending phases of the pushup (8). The Perfect Pushup™ manufacturers suggest it can maximize strength in the arms, shoulders, chest, back and abdominals while reducing joint strain (8, 21).

Many studies rely on surface electromyography (EMG) to assess the neural activation of muscles necessary for producing mechanical movement and strength gains. Exercises that produce higher EMG amplitudes for a given skeletal muscle are assumed to generate greater adaptations in strength over time (3, 22). Muscle activation of shoulder and shoulder girdle muscles has been assessed during bench press exercises, conventional push-ups, and the Perfect Pushup™ (4, 10, 14, 15, 17, 18, 22). In contrast to manufacturers' claims, Youdas et al. reported no significant influence of the Perfect Pushup™ over a conventional push-up for neural activation of upper body musculature when averaged over 3 repetitions (22). This study did suggest an increase in pectoralis major activation by Perfect Pushup™ when using a wide hand base of support in a sample including both men and women (22).

Previous research has suggested that men and women may activate skeletal muscle differently during upper body exercises (1, 2). Specifically, women rely on muscle activation more than men during dynamic movements (2). This study will focus only on men to determine if type of pushup results in changes to muscle activation. Additionally, the effect of different types of push-ups on the neural activity required for each repetition during a multi-repetition set has not been studied. The purpose of this study was to assess neural activity for the upper body musculature in college-age men during 5 repetitions of a conventional pushup or a Perfect Pushup™ when using a wide base of hand support for the upper body. We hypothesized that the Perfect Pushup™ would result in increased neural activation for all muscle tested over 5

repetitions. Additionally, we hypothesized that the Perfect Pushup™ would result in increased activation earlier in the repetition count than the conventional pushup.

METHODS

Participants

Participants consisted of 18 healthy men. Demographic characteristics are provided in Table 1. Participants were required to be physically fit with no upper extremity pathology within the past year (6). Additionally, participants were required to engage in upper extremity resistance training including conventional push-ups at least twice a week (22) for the past 3 months. Volunteers were recruited from classes and student organizations by flyers posted on the university's campus. The Institutional Review Board approved the study protocol and participants gave informed consent before initiation of testing.

Table 1. Demographic characteristics of participants (n = 18).

| | |
|-----------------|---------|
| Age (yrs) | 21.6±1 |
| Height (cm) | 182.5±7 |
| Weight (kg) | 87.4±15 |
| Distance (cm) | 76.9±9 |
| MVIC (kg-force) | 59.0±11 |

Data are Means±standard deviations. Distance, cm between index fingers during hand placement for push-up, MVIC, maximal voluntary isometric contraction in the push-up position.

Protocol

Participants attended two trials separated by a minimum of 48 hours; an orientation session and exercise session. The orientation session began with educating the participants about the purpose of the investigation, having participants sign an informed consent, and receive instructions on proper push-up position and technique.

To standardize hand placement between exercises, the investigator measured the distance from the participants' right and left index finger when the participant's chest wall was elevated from the floor, spine straight, and shoulders flexed 90° relative to the trunk's longitudinal axis and elbows flexed 90° (6, 15, 17, 22). This distance was marked with tape for participant hand placement during the maximal voluntary isometric contraction in the pushup position (MVIC_{PU}), conventional push-up and Perfect Pushup™ exercises (15, 17).

Once instructions were given, participants practiced the MVIC_{PU}, the Perfect Pushup™ and a conventional push-up. MVIC_{PU} was determined in a pushup position with the participant's chest wall elevated from the floor, spine and legs straight, shoulders flexed 90° relative to the trunk's longitudinal axis, and elbows flexed 90°. The barbell of a Fixed Bar Smith Press Machine (Cybex Intl., Model 5341-90, Owatonna, Mn.) was adjusted to the height of participants upper back when in the starting pushup position. The bar was externally loaded to render it immovable by the participant. Using the standardized distance for hand placement, participant placed their hands on two separate 250 x 125 x 22 mm force plates (Biometrics, Ltd., Model FP4, Gwent, UK). Instructions were to press against the stationary barbell with the upper back with moderate to hard effort for several practice trials. This movement resulted in quantifiable force output (kg-force) detected by the force plates beneath the hands.

The start position for both the conventional push-up and the Perfect Pushup™ exercises began with the chest wall elevated from the

floor, spine and legs straight, elbows straight, and shoulders flexed 90 degrees relative to the trunk's longitudinal axis (22). In the start position, forearms and wrists were in the neutral position with fingers extended forward and palms on the floor (22). The exercise was initiated with controlled lowering of the trunk (descending phase) so the sternum made contact to a 10 cm tall foam block placed on the floor under the participant (17, 22). Once contact was made with the foam block, the descending phase was complete and the ascending phase of the push-up began by returning to the start position. In an effort to standardize technique for both the convention and Perfect Pushup™, participants were instructed to inhale in the descending phase and exhale during the ascending phase (6). The participants were also instructed to perform the push-up at one-second per phase, or 2 seconds for one complete repetition, by keeping pace with an audible 60-hz metronome (10, 20, 22). Participants practiced several attempts at the convention push-up. The participant was required to repeat the push-up if they did not descend to the correct depth and make contact with the foam block or failed to maintain pace with the cadence of the metronome.

The Perfect Pushup™ also began in the "up" position with the arms extended, forearms and wrists in neutral position and fingers flexed on the handle of the apparatus (22). The Perfect Pushup™ Basic (Perfect Fitness Canton, OH) apparatus consisted of a soft, cell foam handle, 11.5 cm in height mounted to a circular 18.8 cm diameter, non-slip rotating base. Instructions were the same as the conventional pushup up with participants making contact with the sternum to the 10

cm foam block. During the descending phase, participants rotated the hands externally 90° until the sternum contacted the foam block. Participants then internally rotated the hands 90° while simultaneously returning to the starting position (ascending phase). Participants were instructed to pace the rotational movements such that the rotation ended simultaneously with the end of the ascending or descending phases of the pushup. No EMG data collection or analysis was conducted during the orientation session. The participants rested at least 48 hours before returning for the exercise session (6).

For the exercise session, surface electrodes were used to monitor the neural drive resulting in activation of the pectoralis major (PM), triceps brachii (TB), serratus anterior (SA), and the posterior deltoid (PD) (11, 22) for the participants' dominant arm (10, 20). Raw EMG amplitude was collected using the SX230-1000 electrode sensors, which had a fixed electrode distance of 20mm (Biometrics Ltd., Gwent, UK). The electrodes were placed parallel to the line of action of the triceps brachii, pectoralis major, serratus anterior, and posterior deltoid muscles using previously published protocols (11, 22). Briefly, the triceps brachii electrode was positioned at the midpoint between the posterior aspect of the acromion and the olecranon process. The pectoralis major electrode was placed at the midpoint of the distance between the sternal notch and the axillary fold, whereas the serratus anterior electrode was positioned just anterior to the border of the latissimus dorsi muscle at the level of the inferior tip of the scapula (11, 22). The electrode for the posterior deltoid was angled obliquely toward the deltoid tuberosity. The ground electrode was

positioned over the ulna immediately proximal to the styloid process (10, 15, 17).

Once electrodes were placed, MVIC_{PU} was assessed simultaneously for the four muscles with the participant in the starting pushup position previously described for the orientation session. Participants were instructed to push the upper back into the immovable barbell as hard as possible for 5 seconds (10). The participant performed three trials of MVIC_{PU} and were allowed a five-minute recovery between each MVIC_{PU} (6). Force output (kg-force) was collected by the force plates at 1000 Hz for the 5 second effort (Biometrics Ltd., DataLOG MWX8, Gwent, UK). Additionally, EMG amplitude for the 4 muscles were collected simultaneously using the DataLog MWX8 system. The average EMG amplitude (mV/sec) from the peak MVIC trial was used to standardize the EMG amplitude for the two push-up trials (6).

Once the MVIC_{PU} trials were completed, the testing order of the two push-up exercises was counterbalanced. Participants completed 5 repetitions of the conventional push-up and Perfect Pushup™ using the procedures described in the orientation session. Average EMG amplitude (mV/sec) for the 4 muscles was collected at 1000 Hz per repetition. A 5-min rest interval was given between each exercise (10). In order to minimize any changes to the EMG signal due to electrode placement, all pushup trials were completed on the same day and separated by the 5-min recovery period. Thus, once the electrode was placed on the muscle, it was not moved until the MVIC and both pushup trials had been completed.

Neural activity of the dominant arm was measured for the four muscles studied using pre-amplified, bipolar surface electrodes (SX230-1000, Biometrics, Ltd.). Raw EMG signals were digitized at 1000 Hz and preamplified with a gain $\times 1000$. Data from each input channel were analyzed simultaneously using Biometrics DataLOG software 8.0 with a high pass third order filter (18dB/octave), a low pass filter for removal of frequencies greater than 450Hz, and an eight order elliptical filter (-60dB at 550 Hz) (5). EMG recordings were full wave rectified and converted to root mean square (RMS) using a 250 ms sliding window. The integrated EMG amplitude was measured for the area under the curve of the RMS-EMG (mV/sec). Results were normalized to the integrated RMS-EMG signal detected during the 5 second MVIC trial (%MVIC_{PU}).

Statistical Analysis

Normalized RMS-EMG values were statistically analyzed for each of the muscles included in the study for each of the two push-up conditions. Data were tested and meet the assumption of normality. All statistical analyses were conducted using Statistica 8.0 (StatSoft, Inc., Tulsa, OK). One way ANOVA F-tests were used to determine any significant differences of normalized RMS-EMG of the triceps brachii, serratus anterior, posterior deltoid, and pectoralis major during a Perfect Pushup™ and the conventional push-up during the exercise trials. A 2 \times 3 (pushup condition \times repetition) Repeated Measures ANOVA was used to detect

differences in normalized RMS-EMG between the first, third, and fifth repetitions between pushup types. Any significant interactions or main effects were further tested with a post-hoc Bonferroni adjustment. An alpha level of 0.05 was used to determine statistical significance.

RESULTS

The type of pushup did not affect normalized RMS-EMG (%MVIC_{PU}) for the triceps brachii (PU, 132 \pm 45%; PPU, 106 \pm 40%; $F(1,34) = 3.272$, $p=0.079$) or the serratus anterior (PU, 152 \pm 36%; PPU, 143 \pm 35%; $F(1,34) = 0.589$, $p=0.45$) over the entire 5 repetitions. The Perfect Pushup™ resulted in greater normalized RMS-EMG in the pectoralis major (PU, 90 \pm 25%; PPU, 134 \pm 39%; $p<0.05$) over the 5 repetitions, while the conventional pushup resulted in significantly greater normalized RMS-EMG in the deltoid (PU, 286 \pm 85%; PPU, 210 \pm 74%; $p<0.05$).

When examining the 1st, 3rd, and 5th repetitions separately for each muscle, there was no significant interaction ($F(2,68) = 0.032$, $p = 0.97$) for the type of pushup or repetition number for the triceps brachii on normalized RMS-EMG (Figure 1A). There was a main effect of repetition (Rep1, 105 \pm 39%, Rep3, 117 \pm 47%, Rep5, 134 \pm 50%; $F(2,68)=31.90$, $p <0.05$ for all comparisons) as both types of pushups resulted in greater normalized RMS-EMG by the 5th repetition.

MUSCLE ACTIVATION AND PUSHUP TYPE

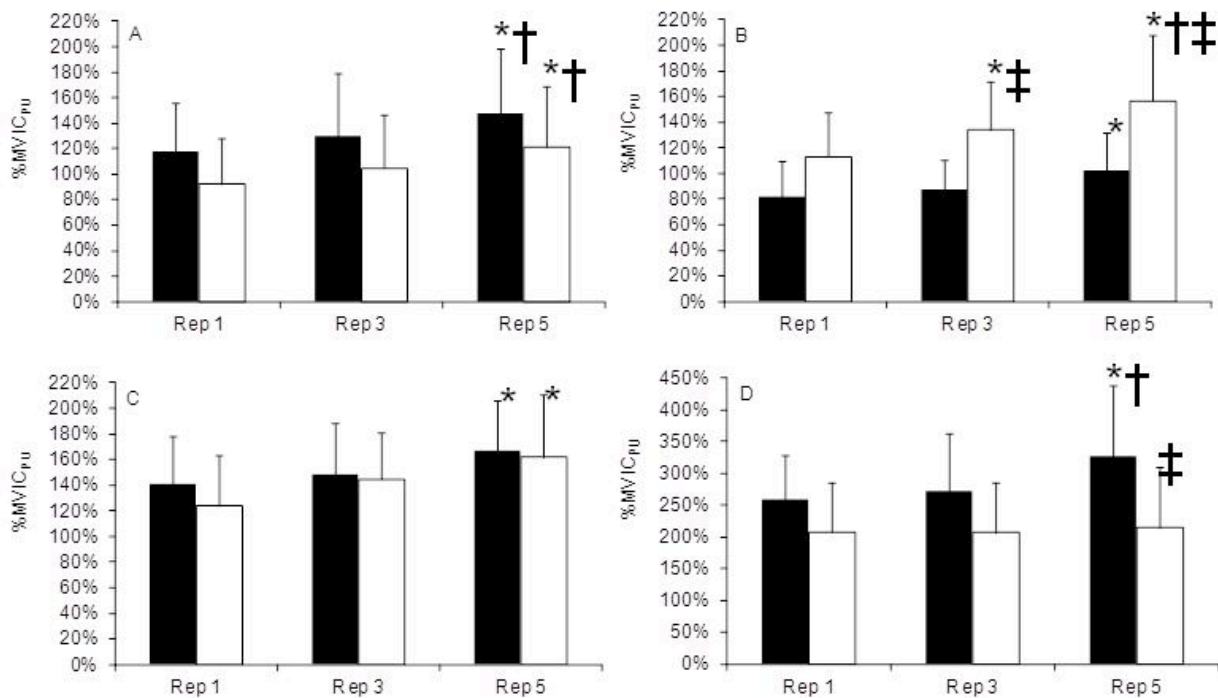


Figure 1. Average normalized electromyography (%MVIC_{PU}) for the A) triceps brachii, B) pectoralis major, C) serratus anterior, and D) posterior deltoid during the 1st, 3rd, and 5th repetitions of a push-up. Black bars, conventional push-up. White bars, Perfect Pushup™. %MVIC_{PU}, average root mean square of the EMG signal (RMS-EMG) for the 2 second pushup movement relative to the RMS-EMG of the maximal voluntary isometric contraction (MVIC) in the pushup position. * different from repetition 1 ($p < 0.05$). † different from repetition 3 ($p < 0.05$). ‡ different from the conventional pushup for the same repetition ($p < 0.05$). Values are means + std dev.

For the pectoralis major, there was a significant interaction of type of pushup and repetition number ($F(2,68)=4.75$, $p < 0.05$); Figure 1B). The conventional pushup did not exhibit any change in normalized RMS-EMG until repetition 5 ($p < 0.05$), while the Perfect Pushup™ increased normalized RMS-EMG by repetitions 3 and 5 ($p < 0.05$). Additionally, the Perfect Pushup™ resulted in greater normalized RMS-EMG than the pushup in repetitions 3 and 5 ($p < 0.05$, Figure 1B). The normalized RMS-EMG of the serratus anterior was not affected by type of pushup ($F(2,68)=0.94$, $p = 0.40$, Figure 1C). There

was a main effect of repetition as both types of pushups resulted in increased normalized RMS-EMG of the serratus anterior by the 5th repetition ($p < 0.05$).

For the posterior deltoid, there was a significant interaction of type of pushup and repetition number ($F(2,68)=4.27$, $p < 0.05$; Figure 1D). The conventional pushup resulted in increased normalized RMS-EMG by repetition 5 ($p < 0.05$), while the Perfect Pushup™ did not cause any changes in normalized RMS-EMG ($p = 0.99$). Additionally, the conventional pushup resulted in greater normalized RMS-EMG

in the 5th repetition than the Perfect Pushup™ ($p < 0.05$, Figure 1D).

DISCUSSION

This study examined several upper body skeletal muscles related to stability and movement of the glenohumeral joint (16). When performing a pushup, the pectoralis major and deltoid are considered to be the primary movers and dynamic stabilizers of the shoulder while the serratus anterior is a stabilizing muscle for the scapula (17). The triceps brachii is primarily an elbow extensor but may be a shoulder stabilizer in more difficult movements (19). This study shows that when using a wide hand base of support for the upper body, changing the type of push-up results in significant changes in the neural activation of the primary movers of the pectoralis major and the posterior deltoid. No significant differences were detected for the stabilizing serratus anterior or the elbow flexor, triceps brachii.

In the data collected with this study design, men exhibit an increased neural activation in the pectoralis major compared to the conventional pushup when using a wide hand base of support for the upper body. A possible explanation for this increase in muscle activation in the pectoralis major due to the Perfect Pushup™ is the change in the depth of the movement. For both trials, participants were instructed to lower the sternum until it came in contact with a foam block 10 cm high. When using the Perfect Pushup™ apparatus, individuals' hands were elevated 11.5 cm above the ground. For participants to adhere to the instructions of touching the foam block, they were required to descend deeper into the movement most likely increasing the

range of motion in the shoulder and elbow joints. This could result in greater neural drive and muscle activation to complete the movement. Previously, the Perfect Pushup™ using a standard hand placement has been shown to increase the range of motion in the elbow along with an increase in EMG in the pectoralis major (7). This study did not examine elbow range of motion while performing the wide base push-ups but does support the previous findings of increased pectoralis major activation with the Perfect Pushup™ using a standard base of upper body support (7). However, the other three muscles studied did not exhibit the same response as the PM suggesting that the depth of movement is not the only factor determining muscle activation between the two types of pushups. Future studies should control for the height of the Perfect Pushup™ apparatus to determine if the rotating movement of the Perfect Pushup™ alone results in greater neural drive to the pectoralis major muscles.

Previous research showed a tendency of increased activation in the PM (9.9%, $p = 0.65$) in a sample consisting of men and women (22). This study shows a significant increase in the neural drive to the pectoralis major in men only. Women may activate muscle differently than men during dynamic upper body muscular contractions. In a study examining sitting push-ups, women used greater normalized muscle activation than men to accomplish the upper body movement (2). This study eliminates a potential confounder of a mixed gender sample and a significant increase in muscle activation was detected in men only. As women tend to have smaller muscle mass than men, greater reliance on activation would be required to

recruit the available fibers necessary for the push-up movement (2). This study design should be replicated in women to determine if the Perfect Pushup™ apparatus and technique would alter the neural drive necessary for completing the push-up exercises.

In the other primary mover and stabilizer of the shoulder (17), the deltoid exhibited greater activation during the conventional push-up. This is a similar finding to Youdas et al., (2010), clearly showing that conventional push-ups require more neural drive to the posterior deltoid to accomplish the exercise (22). The mechanism by which the perfect push-up results in less activation of the posterior deltoid is unclear. As noted previously, it is theorized that the rotational aspect of the movement contributes to increased stability of the shoulder resulting in less neural activation during the Perfect Pushup™ (22). To our knowledge, this stabilization theory has not been tested or published.

No effect of push-up type was noticed for the triceps brachii or serratus anterior. The triceps brachii is primarily an elbow extensor during the push-up (16) and was not affected by the push-up type despite the possibility of greater elbow extension required for the Perfect Pushup™. The triceps brachii can be activated as a shoulder stabilizer in more difficult tasks which may result in greater activation (19); however, there is no evidence to suggest this occurred due to push-up type. The primary role of the serratus anterior is scapular stability, based on the neural activity, this skeletal muscle did not appear to be affected by the type of push-up.

In terms of the time course for the changes over multiple repetitions, all four muscles showed increased neural drive by the 5th repetition during the conventional pushup. The Perfect Pushup™ increased neural activity to the pectoralis major by the third rep. This “early” increase in neural drive by the 3rd repetition was only detected in the pectoralis major and only during the Perfect Pushup™. The Perfect Pushup™ did increase neural drive to the TB, and SA by the 5th rep; however, the Perfect Pushup™ did not alter the neural drive to the deltoid by the 5th rep.

Linear envelope-detected surface electromyography is a technique that can be used to assess the amount of neural activity, specifically EMG amplitude, during a specific time period. Exercises that produce higher EMG amplitudes are assumed to generate greater adaptations in strength over time (3, 22). One model for defining fatigue in muscular performance is detecting an increase in neural activity for moving the same amount of external load (9, 12, 19). As motor units fatigue over multiple repetitions, more fibers are recruited to maintain the level of force output (19). The Perfect Pushup™ resulted in an increased neural drive to the pectoralis major by only the third repetition (21%) with further increases by repetition 5 (23%). This suggests that the overload on the pectoralis major by Perfect Pushup™ movement is more stressful than the conventional pushup. In terms of application, the Perfect Pushup™ should result in greater adaptations to the pectoralis major over multiple weeks of multiple repetitions due to more fibers being activated to accomplish the movement given the same amount of time. In contrast to the pectoralis major, the

Perfect Pushup™ did not alter the neural recruitment of the posterior deltoid over the 5 repetitions. More repetitions of a Perfect Pushup™ would be required to show the fatigue index of increased neural drive to the posterior deltoid.

It is important to note that muscle activation is not a direct measure of muscle strength or adaptations (22). Neural activity can be used to demonstrate which pushup type placed the highest external demand upon a muscle for a given number of repetitions (22). Thus, the type of push-up that requires the greatest neural activity for a given number of repetitions should result in improved adaptations. For this data set, the Perfect Pushup™ was superior to the conventional push-up in terms of activating the pectoralis major. Individuals training for adaptations in the posterior deltoid would elicit more neural activation by conventional push-ups. Future study should examine the impact of more repetitions on neural drive to determine the time-course of changes to the neural drive and motor unit recruitment during the different types of push-ups.

There are several issues that must be considered when interpreting this data. First, this study is limited to only explaining neural changes during a wide base push up. We did not explore other hand placement distances which are known to effect muscle activation of the muscle that were examined (10, 22). Another issue relates to the measurement neural activity of all 4 muscles simultaneously during the MVIC in pushup position. Based on the normalized EMG values being greater than 100%, it is clear that the push-up position MVIC didn't activate each individual muscle as significantly as if each muscle

were independently tested for MVIC. The neural activation of the four muscles for the MVIC was most likely influenced by a mechanical disadvantage for the joint angle used.

Previous research suggests that a certain percentage of MVIC is necessary for adaptations to muscular strength (13, 22). These recommendations are based on comparing the neural drive of a muscle to its neural drive during an isolated maximal contraction. Since this study utilized a positional maximal contraction for normalization, we cannot comment on whether the neural activation detected in this study would result in significant muscle adaptations over time. However, the purpose of the study was not to examine which muscle was activated the most by certain pushup type (22), but to investigate possible changes to the neural drive due to push-up type with a wide base of upper body support. Thus, the push-up position MVIC did serve the purpose of normalizing the data for the pushup movements. All participants gave a maximal effort for the position selected to assess overall MVIC. Additionally, electrode placement can influence EMG recordings and analysis. All electrodes were placed according to published protocols prior to the MVIC and at no point did the EMG sensors move or change location between the three exercises (MVIC, conventional and Perfect Pushup™). By normalizing EMG activity with the pushup position MVIC, individual variability or electrode placement issues should be minimized. Also, the use of precise electrode placement consistent across all three movements should assist in minimizing any erroneous EMG activity or

cross talk from other muscles being activated (22).

Using EMG analysis, we sought to examine the claim of increased muscular recruitment made by the manufacturer. In this study, we examined the EMG activity in four muscles required to perform a wide base conventional push-up or a push-up using the Perfect Pushup™ handgrips in men. There were no differences in muscle activation for either the triceps brachii or the serratus anterior suggesting that neither type of pushup promotes an additional benefit. The Perfect Pushup™ is the appropriate exercise for eliciting the greatest amount of pectoralis major activation over five repetitions while the conventional push-up is superior for activating the posterior deltoid. Future studies should examine possible training adaptations due to different activation patterns based on the type of pushup. In conclusion, trainers and rehabilitation specialists should consider these data when attempting to train or isolate particular upper body skeletal muscles using a push-up movement.

REFERENCES

1. Anders C, Bretschneider S, Bernsdorf A, Erler K, Schneider W. Activation of shoulder muscles in healthy men and women under isometric conditions. *J Electromyogr Kinesiol* 14: 699-707, 2004.
2. Anderson DS, Jackson MF, Kropf DS, Soderberg GL. Electromyographic analysis of selected muscles during sitting push-ups. Effects of position and sex. *Phys Ther* 64: 24-28, 1984.
3. Ayotte NW, Stetts DM, Keenan G, Greenway EH. Electromyographical analysis of selected lower extremity muscles during 5 unilateral weight-bearing exercises. *J Orthop Sports Phys Ther* 37: 48-55, 2007.
4. Barnett C, Kippers V, Turner P. Effects of Variations of the Bench Press Exercise on the EMG Activity of Five Shoulder Muscles. *J Strength Cond Res* 9: 222-227, 1995.
5. Biometrics L. Biometrics Ltd DataLOG MWX8 Operating Manual. Gwent, UK, 2012.
6. Blackard DO, Jensen RL, Ebben WP. Use of EMG analysis in challenging kinetic chain terminology. *Med Sci Sports Exerc* 31: 443-448, 1999.
7. Bohne M, Slack J, Claybaugh T, Cowley J. A Comparison of the Perfect Pushup™ to Traditional Pushup. Presented at International conference on Biomechanics in Sports, Limerick, Ireland, 2009.
8. Calzaretta S. The Benefits of using the Perfect Pushup with Wrist Injuries. 2013, 2009.
9. Carpentier A, Duchateau J, Hainaut K. Motor unit behaviour and contractile changes during fatigue in the human first dorsal interosseus. *J Physiol* 534: 903-912, 2001.
10. 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* 19: 628-633, 2005.
11. Criswell E. Cram's Introduction to surface electromyography. Sudbury, MA: Jones and Bartlett, 1998.
12. Decker MJ, Hintermeister RA, Faber KJ, Hawkins RJ. Serratus anterior muscle activity during selected rehabilitation exercises. *Am J Sports Med* 27: 784-791, 1999.
13. Digiovine NM, Jobe FW, Pink M, Perry J. An electromyographic analysis of the upper extremity in pitching. *J Shoulder Elbow Surg* 1: 15-25, 1992.
14. Ebben WP, Wurm B, VanderZanden TL, Spadavecchia ML, Durocher JJ, Bickham CT, Petushek EJ. Kinetic analysis of several variations of push-ups. *J Strength Cond Res* 25: 2891-2894, 2011.
15. Gouvali MK, Boudolos K. Dynamic and electromyographical analysis in variants of push-up exercise. *J Strength Cond Res* 19: 146-151, 2005.

MUSCLE ACTIVATION AND PUSHUP TYPE

16. Houglum PA, Bertoti DB. *Brunnstrom's Clinical Kinesiology*. Philadelphia, PA: F.A. Davis Company, 2012.
17. Lear LJ, Gross MT. An electromyographical analysis of the scapular stabilizing synergists during a push-up progression. *J Orthop Sports Phys Ther* 28: 146-157, 1998.
18. Ludewig PM, Hoff MS, Osowski EE, Meschke SA, Rundquist PJ. Relative balance of serratus anterior and upper trapezius muscle activity during push-up exercises. *Am J Sports Med* 32: 484-493, 2004.
19. Pontillo M, Orishimo KF, Kremenec IJ, McHugh MP, Mullaney MJ, Tyler TF. Shoulder musculature activity and stabilization during upper extremity weight-bearing activities. *N Am J Sports Phys Ther* 2: 90-96, 2007.
20. Uhl TL, Carver TJ, Mattacola CG, Mair SD, Nitz AJ. Shoulder musculature activation during upper extremity weight-bearing exercise. *J Orthop Sports Phys Ther* 33: 109-117, 2003.
21. www.perfectonline.com. Perfect Pushup Elite. 2013.
22. 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* 24: 3352-3362, 2010.