Bench Press and Push-up at Comparable Levels of Muscle Activity Results in Similar Strength Gains

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Abstract

Calatayud, J, Borreani, S, Colado, JC, Martin, F, Tella, V, and Andersen, LL. Bench press and push-up at comparable levels of muscle activity results in similar strength gains. *J Strength Cond Res* 29(1): 246–253, 2015—Electromyography (EMG) exercise evaluation is commonly used to measure the intensity of muscle contraction. Although researchers assume that biomechanically comparable resistance exercises with similar high EMG levels will produce similar strength gains over the long term, no studies have actually corroborated this hypothesis. This study evaluated EMG levels during 6 repetition maximum (6RM) bench press and push-up, and subsequently performed a 5-week training period where subjects were randomly divided into 3 groups (i.e., 6RM bench press group, 6RM elastic band push-up group, or control group) to evaluate muscle strength gains. Thirty university students with advanced resistance training experience participated in the 2-part study. During the training period, exercises were performed using the same loads and variables that were used during the EMG data collection. At baseline, EMG amplitude showed no significant difference between 6RM bench press and band push-up. Significant differences among the groups were found for percent change (Δ) between pretest and posttest for 6RM ($p = 0.017$) and for 1 repetition maximum (1RM) ($p < 0.001$). Six repetition maximum bench press group and 6RM elastic band push-up group improved their 1RM and 6RM (Δ ranging from 13.65 to 22.21) tests significantly with similar gains, whereas control group remains unchanged. Thus, when the EMG values are comparable and the same conditions are reproduced, the aforementioned exercises can provide similar muscle strength gains.

Key Words electromyography, elastic bands, intensity, resistance training, 6RM

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Introduction

The bench press and the push-up are 2 classic push exercises for strengthening the upper body (7,18) also used to asses maximal muscular strength (7) or muscular endurance (2,20,24), respectively. In addition, the biomechanical similarities between these exercises have been established several years ago (8). Although the bench press usually requires expensive equipment, the push-up can be performed anywhere. The advantage of bench press is the possibility for low, moderate, and high training intensities, whereas load during traditional push-up is determined by body weight (8).

Intensity is cardinal in training progressions (18), and high intensities (>80% of 1 repetition maximum [1RM]) are recommended to maximize muscular strength gains in advanced lifters (3). Performing push-ups with bodyweight only is unlikely to provide sufficient training stimulus in advanced trainees. Thus, added resistance may be needed for push-ups to be effective beyond the initial training stage. Because of their low cost, adaptability, and portability (26), elastic resistance has become a feasible alternative to traditional resistance training (31). Furthermore, elastic resistance proved effective in inducing comparable electromyography (EMG) levels as those achieved with free weights or training machines during lower-body (22,23,26) and upper-extremity resistance exercises (1,4). Hence, added elastic resistance may be sufficient for effective high-intensity push-up training.

Electromyography exercise evaluation is frequently used to examine the intensity of muscular activity (4,5,27) and consequently estimate the effectiveness of different exercises. Heavy resistance exercise induces relatively high levels of muscle activity (5,27), which over a training period induce muscle strength gains (27) and may improve athletic performance, musculoskeletal health, and alter body aesthetics (19). Thus, researchers generally assume that exercises with higher EMG levels provide greater muscle strength gains during a training period (5,6,16). Indeed, despite the percentage of maximal activity is influenced by several variables (14), it is considered that the level of EMG activation should reach 60% to induce muscle strength and structural adaptation (5). This assumption has been used during years in several articles

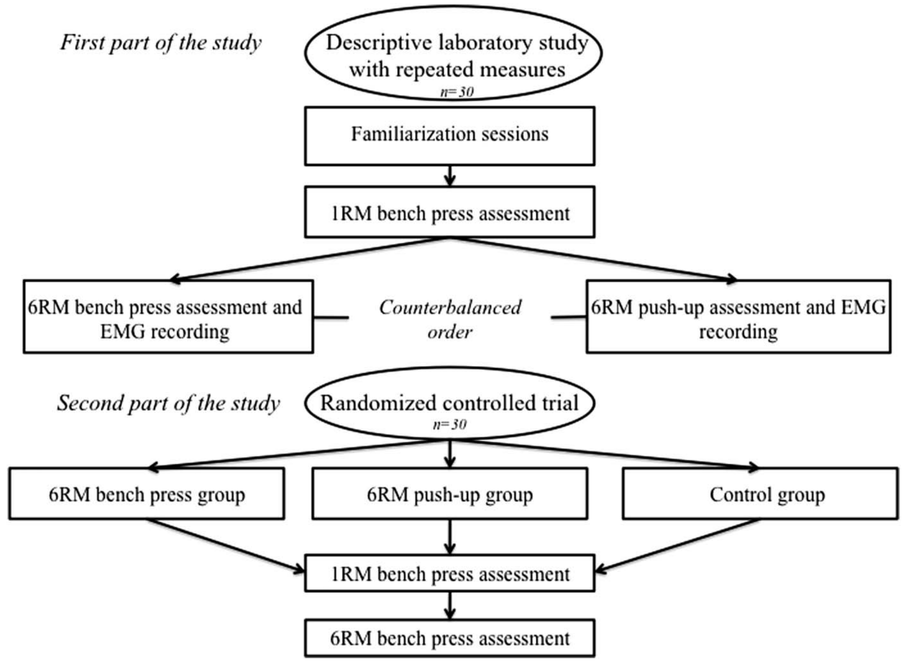

Figure 1. Study scheme. 1RM = 1 repetition maximum; 6RM = 6 repetition maximum; EMG = electromyography.

where exercises with EMG values over this threshold were considered as effective to promote muscle strength adaptations (6,16,32,33). Likewise, biomechanically comparable exercises that yield similar EMG levels are assumed to be equally effective and capable of producing similar strength gains (4,8). However, previous studies have been conducted to analyze either EMG values or to evaluate muscle strength gains after an exercise program rather than integrating both pathways, so the effects of applying an exercise with a certain percentage of maximum voluntary isometric contraction (%MVIC) in the same subjects is only an assumption. Hence, no studies have evaluated muscle activity during a given exercise and subsequently performed a training program to corroborate these hypotheses. Therefore, the purpose of this study was twofold: (a) to evaluate the EMG levels during 6 repetition maximum (6RM) bench press and push-up and (b) to evaluate the strength gains after a training period with either the bench press or push-ups with the same loads and variables (i.e., intensity, volume, rest, exercise technique, and speed of movement) that were used during the data collection. We hypothesized that the 6RM bench press and the 6RM push-ups would induce similar EMG levels. In addition, we hypothesized that these exercises also would lead to similar muscle strength gains after the training program.

Methods

Experimental Approach to the Problem

Thirty volunteers participated in a 2-part study. To examine the first aim of the study and determine the intensity of the exercises as a %MVIC, subjects took part in a repeated measures design assessment. In the first 2 sessions, the subjects were familiarized with the protocol; in the third session, they performed a 1RM, and in the fourth session, they performed two 6RM with EMG data collection. Surface EMG signals were recorded from the muscles: sternocostal head of the pectoralis major (PEC) and anterior deltoid (ADELT). The data obtained were normalized by using the mean root mean square (RMS) values during the MVIC and expressed as a percentage of the maximum EMG. Afterward, to examine the second aim of the study and determine the effectiveness of the exercises that were previously measured through EMG, subjects took part in a randomized control trial, performing a 5-week training program of either bench press or push-ups with the same loads and variables that were used during the data collection. Finally, the subjects performed 1RM and 6RM bench press tests in separate sessions. The study design attempted to answer the following research question: "Do 2 biomechanically comparable exercises–the push-up and bench press–performed at the same relative intensity, as defined by relative EMG amplitude, result in similar strength gains?" A visual of the design is presented in Figure 1.

Subjects

Young university students (22 men and 8 women ranging from 19 to 27 years old) voluntarily participated in this study. Subject characteristics are presented in Table 1. All subjects had experience using the bench press or the push-up, and they had experience in the use of elastic resistance during the push-up exercise since they used this variation in a previous study conducted in the same laboratory. Before beginning with the study, they were not involved in a training program using 6RM loads so they were not familiarized with such intensity. However, participant's training status was considered advanced according to the National Strength and Conditioning Association (NSCA) classification, since they had a minimum of 1 year of resistance training experience, performing at least 3 sessions per week at moderate/high intensity, and they were currently training (7). No significant differences between the training status and the 1RM and 6RM baseline loads were reported among the different groups (Table 1).

None of the participants were taking any medications or anabolic steroids that could influence in the outcomes, and none of the participants had musculoskeletal pain, neuromuscular disorders, or any form of joint or bone disease. All participants signed an institutional informed consent form before starting the protocol, and the institutions' review board approved the study. All procedures described in this section comply with the requirements listed in the 1975 Declaration of Helsinki and its amendment in 2008.

Procedures

Each participant took part in 16 sessions in the following order: 2 familiarization sessions, a 1RM bench press test session, two 6RM tests with EMG data collection, 10 training sessions, a post-1RM bench press estimation session, and lastly a post-6RM bench press estimation session. These sessions were performed at the same time during the morning (i.e., between 9 AM and 1 PM), separated by 2 days. The same investigators performed all measurements, and the procedures were always conducted in the same facility at 20° C. The study was done during February to March 2013.

Several restrictions were imposed on the volunteers before the sessions: no food, drinks, or stimulants (e.g., caffeine) to be consumed 3 hours before the sessions and no physical activity more intense than daily activities 24 hours before the exercises. They were instructed to sleep more than 8 hours the night before data collection.

During the training period, all the subjects were asked to maintain their normal diet and their usual sport practices, avoiding additional activity or changes in the training program that could influence the results so they had to maintain the volume and the training intensity that were using before beginning their participation in the study. In addition, the 2 intervention groups were asked to refrain from additional training involving the PEC or pushing movements. In addition, they were instructed to consume water ad lib during the exercise performance to ensure hydration (28).

Familiarization Session. During the familiarization sessions, the participants were familiarized with the different exercises, movement amplitude, body position, and cadence of movement that would later be used during data collection. Participants practiced the exercises until they felt confident, and the researcher was satisfied with their technical execution. Moreover, height (IP0955; Invicta Plastics Limited, Leicester, England), body mass, body fat percentages (Tanita model BF-350; Tanita, Tokyo, Japan), and biacromial width were obtained according to the protocols used in previous studies (20).

One Repetition Maximum Strength Testing Sessions. Before the 1RM test, subjects performed mobility drills without ballistic movements to warm up. The testing sessions were separated by 2 days. The estimation of the 1RM during the bench press in the Smith machine was performed according to the NSCA's protocol (7). The same bench press technique was used on all test and training sessions. Three to 5 attempts were used to measure each 1RM to avoid fatigue and compromise the accuracy of the test (21). Subjects were positioned supine with the head and trunk supported by the bench, the knees bent, the feet flat on the bench, the elbow flexed 90°, and the shoulder abducted 45°. A standardized grip width of biacromial width distance +50% was measured (distance in centimeters between the tips of right and left

Table 1. Subjects characteristics.*

	N	Gender	Age (y)	Height (cm)	Weight (kg)	Body fat (%)	Biacromial distance	Strength experience (y)
Control	10	M = 7; F = 3	21.9 (2.1)	171.6 (7.6)	67.5 (6.3)	13.9 (6.5)	41.2 (3.0)	1.9 (1.9)
Elastic band	10	M = 8; F = 2	20.6 (1.7)	175.4 (6.8)	74.7 (8.0)	13.9 (5.9)	43.2 (2.6)	1.9 (2.9)
Bench press	10	M = 7; F = 3	22.7 (3.3)	173.1 (7.0)	67.7 (8.8)	13.6 (6.1)	42.4 (3.5)	2.4 (2.8)
Total	30	M = 22; F = 8	21.9 (2.4)	172.8 (7.6)	70.6 (8.9)	14.0 (5.8)	42.2 (3.1)	2.1 (2.4)

*Data are expressed as mean (*SD*).

Figure 2. Six repetition maximum elastic-resisted push-up test.

third digits) and used in every session and condition. At the same time, a researcher was located at the head end of the bench during the test to help in raising the bar on a failed attempt and to help the participant place the bar back on the rack (21). After the 5-week training period, the 1RM test was performed similarly to the pretraining test to examine the strength gains.

Six Repetition Maximum Strength Testing Sessions and Electromyography Data Collection. The 2 pre-6RM estimations and the EMG data collection were performed in the same session. The protocol started with a light warm-up, where each subject performed 5 minutes of mobility drills without ballistic movements. Then, the protocol continued with the preparation of participants' skin, and followed by electrode placement, MVIC collection, and exercise performance. Hair was removed with a razor from the skin overlying the muscles of interest, and the skin was then cleaned by rubbing with cotton wool dipped in alcohol for the subsequent electrode placement, positioned according to the recommendations of Cram et al. (14) on the sternocostal head of the pectoralis major (PEC) and anterior deltoid (ADELT), on the dominant side of the body. Pregelled bipolar silver/silver chloride surface electrodes (Blue Sensor M-00-S; Medicotest, Olstykke, Denmark) were placed with an interelectrode distance of 25 mm. The reference electrode was placed approximately 10 cm from the electrode pair, according to the manufacturer's specifications. Participants then performed 1 standard push-up on the floor to check signal saturation. All signals were acquired at a sampling frequency of 1 kHz, amplified, and converted from analog to digital. All EMG signals were stored on a hard drive for later analysis. To acquire the surface EMG signals produced during exercise, an ME6000P8 (Mega Electronics, Ltd., Kuopio, Finland) biosignal conditioner was used.

Before the test described below, two 5-second MVICs were performed for each muscle, and the trial with the highest EMG was selected (4). Participants performed 1 practice trial to ensure that they understood the task. One-minute rest was given between each MVIC, and standardized verbal encouragement was provided to motivate all participants to achieve maximal muscle activation. Positions for the MVICs were performed according to standardized procedures, chosen based on commonly used muscle testing positions for the (a) PEC (8,30) and (b) ADELT (17) and were performed against a fixed immovable resistance (i.e., Smith machine). Specifically: (a) bench press with the previously mentioned technique and (b) shoulder flexion at 90° in a seated position, an erect posture with no back support.

At the end of the MVICs, subjects were rested during 3 minutes and were assigned to the 6RM push-up testing or the 6RM bench press in a counterbalanced order. Both tests were performed separated by 10 minutes of rest and were performed with the aforementioned bench press technique. In addition, a 2:2 ratio (i.e., 2-second rate for descent and 2-second rate for ascent) was maintained by a 30-Hz metronome (Ableton Live 6; Ableton AG, Berlin, Germany) to standardize speed of movement. Visual and verbal feedback was given to the participants to maintain the range of movement and hand distance during the data collection. A trial was discarded and repeated if participants were unable to perform the exercise with the correct technique and cadence. If this occurred, the last EMG recording was deleted. The set when the 6RM was achieved was recorded to analyze EMG data. The 6RM tests were determined in 3–5 attempts, and rest periods between attempts were progressively increased from 1 to 4 minutes according to an established 1RM bench press protocol (7).

For the 6RM bench press testing, 3 warm-up sets were performed on a stable bench in the Smith machine: (a) 20 repetitions at 25% of the previously estimated 1RM, (b) 10 repetitions at 50% of 1RM, and (c) 8 repetitions at 70% of 1RM (7). After these sets, load was estimated and adjusted for the subjects to reach their 6RM. The rationale for using the Smith machine was the absence of muscle activity differences for anterior deltoid and pectoralis major during the

Table 2. Mean and peak muscle activation between conditions ($n = 30$).*†

	Mean (%MVIC)		Peak (%MVIC)	
	PEC	DELT	PEC	DELT
Elastic bands	52.90 (2.55)	62.32 (2.87)	139.73 (6.87)	139.69 (6.10)
Bench press	52.70 (1.85)	59.53 (3.54)	139.98 (6.66)	139.28 (7.70)

*%MVIC = percentage of maximum voluntary isometric contraction; PEC = sternocostal head of the pectoralis major; DELT = anterior deltoid.
†Data are expressed as a mean (*SEM*) in percentage of the MVICs.

free weight bench and the Smith machine bench press, regardless of load or the experience level of the subjects (29).

For the 6RM push-up test, elastic resistance was progressively increased by adding the required number of bands until the subjects were able to perform only 6 reps. Thera-Band elastic band (Hygenic Corporation, Akron, OH, USA) of the colors blue, silver, and gold were used and combined to reach the 6RM push-up. The elastic band grip was performed at 0.70 m of the total band length. A research assistant helped the participants placing the band behind their back with the aforementioned length. Then, participants stretched the band to perform the exercise with the proper grip width (i.e., biacromial width distance +50%). During the 6RM push-up testing, participants started the exercise in an extended arm position with forearms and wrists pronated, feet at biacromial (shoulder) width, and fingers flexed. Hip and spine were maintained neutral during all the repetitions. Figure 2 shows the 6RM elastic-resisted push-up.

After testing, subjects were randomly divided into 3 groups (6RM bench press group, 6RM elastic band push-up group, or control group) and initiated the 5-week training program.

Training Period. During the training period, all variables were established and controlled to exhaustively mimic the EMG session. Thus, the same Smith machine that was used during the test was also used during the training program by the 6RM bench press group. The training program had a frequency of 2 sessions per week, conducted on Mondays and Wednesdays with each session lasting approximately 25 minutes. Each session comprised 5 sets of 6 repetitions with the same load/resistance that was used to reach the 6RM during the EMG session and was maintained during all training sessions. Moreover, the same rest, speed of movement, exercise technique, and grip width than in the previous sessions were used. Rest between sets was maintained in 4 minutes during all the training period to maintain the required number of repetitions on each set without reductions in the established load/resistance (15). All the training sessions were supervised by a certified strength and conditioning specialist accredited and a research assistant. The control group was instructed to perform their usual tasks during the intervention period.

Table 3. Bench press 6RM (kg) at baseline and after 5 weeks.*†

	Pretest	Posttest	Δ (%)	p	p interaction
Control	52.51 (20.49)	53.59 (19.87)	2.72 (0.08)	0.344	0.007
Elastic band	53.20 (13.59)	62.57 (11.51)‡	21.04§ (0.22)	<0.001	
Bench press	57.70 (18.45)	69.95 (21.07)‡	22.21§ (0.13)	<0.001	

*6RM = 6 repetition maximum.
†Data are expressed as mean (*SD*).
‡Significant difference to baseline.
§Different ($p \leq 0.05$) from control group.

Statistical Analyses

All surface EMG signal analyses were performed using Matlab 7.0 (Mathworks, Inc., Natick, MA, USA). Surface EMG signals related to isometric exercises were analyzed by using the 3 middle seconds of the 5-second isometric contraction. The EMG signals of the dynamic exercises were analyzed by taking the average of the entire 6 repetitions. All signals were bandpass filtered at a 20- to 400-Hz cutoff frequency with a fourth-order Butterworth filter. Surface EMG amplitude in the time domain was quantified by using RMS and processed every 100 milliseconds. Mean and peak RMS values were selected for every trial and normalized to the maximum EMG (%MVIC). Mean values of the %MVIC of the ADELT and PEC were calculated and analyzed. Statistical analysis was accomplished using SPSS version 19 (SPSS, Inc., Chicago, IL, USA). All variables were found to be normally distributed (Shapiro-Wilk normality test) before data analysis. Results are reported as mean ± *SE*. Statistical comparisons for muscle activation between the conditions were performed using paired sample *t*-tests. The training-related effects were assessed using repeated measures 2-way analysis of variance (factors: group and time). In

Table 4. Bench press 1RM (kg) at baseline and after 5 weeks.*†

	Pretest	Posttest	Δ (%)	p	p interaction
Control	64.45 (26.82)	65.57 (27.48)	1.68 (0.02)	0.497	<0.001
Elastic band	66.75 (13.71)	75.33 (13.98)‡	13.65§ (0.14)	<0.001	
Bench press	70.64 (20.05)	83.70 (23.57)‡	19.84§ (0.20)	<0.001	

*1RM = 1 repetition maximum.
†Data are expressed as mean (*SD*).
‡Significant difference to baseline.
§Different ($p \leq 0.05$) from control group.

addition, 1-way independent analysis of variance was used to assess percent change (Δ) differences among the 3 different groups. Post hoc analysis with Bonferroni correction was used in the case of significant main effects. Significance was accepted when $p \leq 0.05$.

Results

PEC (mean: $p = 0.927$; peak: $p = 0.968$) and DELT (mean: $p = 0.244$; peak: $p = 0.934$) EMG values showed no significant difference between the 6RM bench press and the 6RM push-up. Results are reported in Table 2. No significant differences have been found between groups at baseline. In regard of the intervention results, there were significant interactions in the 6RM ($p = 0.007$) and 1RM ($p < 0.001$) tests. Significant differences among the groups have been found for percent change (Δ) for 6 RM ($p = 0.017$) and for 1 RM ($p < 0.001$). Six repetition maximum bench press group and 6RM elastic band push-up group improved their 1RM and 6RM tests significantly with similar gains, whereas control group remains unchanged. Results are reported in Tables 3 and 4.

Discussion

This is the first study combining EMG exercise evaluation with a subsequent training period to compare strength gains between 2 different resistance exercises performed with similar intensity, volume, rest, exercise technique, and speed of movement. Our study shows that push-ups with added elastic resistance induces similar high levels of muscle activity and strength gains as the more popular Smith machine bench press.

In our study, the 6RM bench press and the 6RM push-up induced equally activation for the PEC and DELT. In line with this, elastic resistance and dumbbells showed comparable levels of muscle activation during several assistance exercises that target neck, shoulder, forearm (4), biceps brachii (1), and quadriceps (26) muscles. A relationship between similar muscle activation and similar muscle strength adaptations has been assumed for years in EMG studies (4,8), although their verification through a resistance training intervention remained uninvestigated. Thus, the main finding in our study was that the comparable levels of muscle activation during both exercises also were transformed in comparable muscle strength gains after a short-term resistance program. In addition, since EMG levels below the threshold of 60% MVIC has been considered ineffective to produce strength adaptations (5), another relevant and novel finding in our study is that lower EMG values (i.e., 52% MVIC) induced a high-intensity stimulus, which were adequate to produce muscle strength gains.

In line with our findings, Kraemer et al. (25) found that elastic bands were capable of providing a heavy resistance stimulus during a training program. In the same vein, some studies were conducted to compare adaptations between elastic vs. other resistance training methods. For instance, short-term training program showed the efficacy of elastic resistance to produce comparable strength adaptations to those obtained from weight machines among sedentary middle-aged woman (11). A resistance training program using elastic resistance or weight machines and free weights demonstrated also equivalent isometric force improvements among fit young women (10). Moreover, Colado et al. (12) found comparable improvements in body composition, physical fitness, and blood chemistry after 24 weeks in which middle-aged women were involved in elastic resistance training program or a water-based strength training program. In this regard, we found that the elastic-resisted push-up group and the bench press group improved their 6RM bench press test and their 1RM bench press test to a similar extent.

Our results show that biomechanically comparable exercises yield similar EMG levels and muscle strength gains when they are performed under the same conditions, that is, intensity, volume, rest, exercise technique, and speed of movement. Greater strength improvements could be expected due to a possible greater training transference in the bench press group since they were tested and trained in the same exercise and the same Smith machine. In addition, there are some differences between the exercises that could have influenced the results. For example, the performance of the bench press in the Smith machine provides a stable condition (29) and allows a less natural weight lifting than nonguided variations (13). However, our results suggest that these differences between the exercises seem to have less importance than the biomechanical similarities. Indeed, despite strength improvements are dependent of the specific exercise that is performed (19), the biomechanical similarities during the both exercises that were performed in our study (8) could explain the muscle strength transference that was achieved during the bench press test after an elastic-resisted push-up training program.

A previous study failed to report improvements in the 1RM bench press and the push-up endurance muscular test after a push-up training program (9). Nevertheless, in that study, the training intensity may not have been high enough to produce strength adaptations in advanced lifters. Our study demonstrated that the push-up may reach an adequate intensity to induce muscle strength adaptations with the use of additional elastic resistance in advanced participants.

The data provided may not be extrapolated to other populations, with other exercises involving different conditions or muscles. Furthermore, the use of a periodization fashion could lead to different results, despite we considered that for our purpose, the performance of the same variables during all the training program was needed to mimic the EMG test session. Additionally, it should be taken into account that the %MVIC is influenced by several variables like the normalization technique that is used for the MVICs (14,17) and thus, it is difficult to use a concrete muscle activation threshold and establish comparisons between muscle activation levels across different studies.

The 5 weeks of training was sufficient to induce strength improvements likely due to neurological adaptations (3,19). Nevertheless, Future studies should compare the effectiveness of the 2 training methods, especially in longer training programs and should investigate the relationship between EMG and strength adaptations to improve the practical application of the EMG studies. However, to the best of our knowledge, this is the first study aiming to estimate the muscle strength adaptations by integrating and applying the EMG measurements with a subsequent training program. Importantly, our study validates the use of EMG to select effective resistance exercises to promote strength gains in trained individuals.

Practical Applications

Elastic-resisted push-ups induce similar muscle activations levels and strength gains as the bench press when these exercises are performed under the same conditions (i.e., intensity, volume, rest, exercise technique, and speed of movement). Hence, when the same conditions are reproduced and the aforementioned exercises reach the required intensity, comparable EMG values result in comparable muscle strength gains.

The push-up exercise with added elastic resistance provide a feasible and cost-effective option that may be performed anywhere and may be used as an alternative to traditional bench press exercise to provide a high-intensity stimulus in the prime movers involved in the action and produce maximal strength adaptations. Physical therapists and strength and conditioning specialists may use this information to select or include one of the both exercises performed during a resistance training program. Practitioners must be aware that even EMG values below 60% MVIC can produce a high-intensity stimulus and the assumption of this threshold could lead to under/overestimate the results and thus provide wrong conclusions. These data provide information that may have direct implications in athletic performance and musculoskeletal health and contribute to improve the criterion to select optimal exercises when only EMG data are available.

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References

1. Aboodarda, SJ, Hamid, MSA, Muhamed, AMC, Ibrahim, F, and Thompson, M. Resultant muscle torque and electromyographic activity during high intensity elastic resistance and free weight exercises. *Eur J Sport Sci* 13: 155–163, 2013.
2. American College of Sports Medicine. *ACSM's Guidelines for Exercise Testing and Prescription* (8th ed.). Philadelphia, PA: Lippincott Williams & Wilkins, 2010.
3. American College of Sports Medicine. American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. *Med Sci Sports Exerc* 41: 687–708, 2009.
4. Andersen, LL, Andersen, CH, Mortensen, OS, Poulsen, OM, Bjørnlund, IB, and Zebis, MK. Muscle activation and perceived loading during rehabilitation exercises: Comparison of dumbbells and elastic resistance. *Phys Ther* 90: 538–549, 2010.
5. Andersen, LL, Magnusson, SP, Nielsen, M, Haleem, J, Poulsen, K, and Aagaard, P. Neuromuscular activation in conventional therapeutic exercises and heavy resistance exercises: Implications for rehabilitation. *Phys Ther* 86: 683–697, 2006.
6. Ayotte, NW, Stetts, DM, Keenan, G, and Greenway, EH. Electromyographical analysis of selected lower extremity muscles during 5 unilateral weight-bearing exercises. *J Orthop Sports Phys Ther* 37: 48–55, 2007.
7. Baechle, Earle and Wathen, Dan. Resistance training. In: *Essentials of Strength Training and Conditioning* (3rd ed.). T.R. Baechle and R.W. Earle, eds. Champaign, IL: Human Kinetics, 2008. pp. 381–411.
8. Blackard, DO, Jensen, RL, and Ebben, WP. Use of EMG analysis in challenging kinetic chain terminology. *Med Sci Sports Exerc* 31: 443–448, 1999.
9. Chulvi-Medrano, I, Martínez-Ballester, E, and Masiá-Tortosa, L. Comparison of the effects of an eight-week push-up program using stable versus unstable surfaces. *Int J Sports Phys Ther* 7: 586–594, 2012.
10. Colado, JC, Garcia-Masso, X, Pellicer, M, Alakhdar, Y, Benavent, J, and Cabeza-Ruiz, R. A comparison of elastic tubing and isotonic resistance exercises. *Int J Sports Med* 31: 810–817, 2010.
11. Colado, JC and Triplett, NT. Effects of a short-term resistance program using elastic bands versus weight machines for sedentary middle-aged women. *J Strength Cond Res* 22: 1441–1448, 2008.
12. Colado, JC, Triplett, NT, Tella, V, Saucedo, P, and Abellan, J. Effects of aquatic resistance training on health and fitness in postmenopausal women. *Eur J Appl Physiol* 106: 113–122, 2009.
13. Cotterman, ML, Darby, LA, and Skelly, WA. Comparison of muscle force production using the Smith machine and free weights for bench press and squat exercises. *J Strength Cond Res* 19: 169–176, 2005.

14. Cram, JR, Kasman, GS, and Holtz, J. *Introduction to Surface Electromyography.* Gaithersburg, MD: Aspen Publishers, 1998.
15. de Salles, BF, Simão, R, Miranda, F, Novaes Jda, S, Lemos, A, and Willardson, JM. Rest interval between sets in strength training. *Sports Med* 39: 765–777, 2009.
16. Distefano, LJ, Blackburn, JT, Marshall, SW, and Padua, DA. Gluteal muscle activation during common therapeutic exercises. *J Orthop Sports Phys Ther* 39: 532–540, 2009.
17. Ekstrom, RA, Soderberg, GL, and Donatelli, RA. Normalization procedures using maximum voluntary isometric contractions for the serratus anterior and trapezius muscles during surface EMG analysis. *J Electromyogr Kinesiol* 15: 418–428, 2005.
18. Fleck, SJ and Kraemer, WJ. *Designing Resistance Training Programs.* Champaign, IL: Human Kinetics, 2004.
19. Folland, JP and Williams, AG. The adaptations to strength training: Morphological and neurological contributions to increased strength. *Sports Med* 37: 145–168, 2007.
20. García-Massó, X, Colado, JC, González, LM, Salvá, P, Alves, J, Tella, V, and Triplett, NT. Myoelectric activation and kinetics of different plyometric push-up exercises. *J Strength Cond Res* 25: 2040–2047, 2011.
21. Harman, E and Garhammer, J. Administration, scoring, and interpretation of selected tests. In: *Essentials of Strength Training and Conditioning* (3rd ed.). T.R. Baechle and R.W. Earle, eds. Champaign, IL: Human Kinetics, 2008. pp. 249–273.
22. Jakobsen, MD, Sundstrup, E, Andersen, CH, Aagaard, P, and Andersen, LL. Muscle activity during leg strengthening exercise using free weights and elastic resistance: Effects of ballistic vs controlled contractions. *Hum Mov Sci* 32: 65–78, 2013.
23. Jakobsen, MD, Sundstrup, E, Andersen, CH, Persson, R, Zebis, MK, and Andersen, LL. Effectiveness of Hamstring knee rehabilitation exercise performed in training machine vs. elastic resistance: Electromyography evaluation study. *Am J Phys Med Rehabil* 93: 320–327, 2014.
24. Knapik, JJ, Sharp, MA, Canham-Chervak, M, Hauret, K, Patton, JF, and Jones, BH. Risk factors for training-related injuries among men and women in basic combat training. *Med Sci Sports Exerc* 33: 946–954, 2001.
25. Kraemer, WJ, Keuning, M, Ratamess, NA, Volek, JS, McCormick, M, Bush, JA, Nindl, BC, Gordon, SE, Mazzetti, SA, Newton, RU, Gómez, AL, Wickham, RB, Rubin, MR, and Hakkinen, K. Resistance training combined with bench-step aerobics enhances women's health profile. *Med Sci Sports Exerc* 33: 259–269, 2001.
26. Matheson, JW, Kernozek, TW, Fater, DCW, and Davies, GJ. Electromyographic activity and applied load during seated quadriceps exercises. *Med Sci Sports Exerc* 33: 1713–1725, 2001.
27. Ratamess, NA. Adaptations to anaerobic training programs. In: *Essentials of Strength Training and Conditioning* (3rd ed.). T.R. Baechle and R.W. Earle, eds. Champaign, IL: Human Kinetics, 2008. pp. 93–118.
28. Ratamess, NA, Chiarello, CM, Sacco, AJ, Hoffman, JR, Faigenbaum, AD, Ross, RE, and Kang, J. The effects of rest interval length on acute bench press performance: The influence of gender and muscle strength. *J Strength Cond Res* 26: 1817–1826, 2012.
29. Schick, EE, Coburn, JW, Brown, LE, Judelson, DA, Khamoui, AV, Tran, TT, and Uribe, BP. A comparison of muscle activation between a Smith machine and free weight bench press. *J Strength Cond Res* 24: 779–784, 2010.
30. Snyder, BJ and Fry, WR. Effect of verbal instruction on muscle activity during the bench press exercise. *J Strength Cond Res* 26: 2394–2400, 2012.
31. Sundstrup, E, Jakobsen, MD, Andersen, CH, Zebis, MK, Mortensen, OS, and Andersen, LL. Muscle activation strategies during strength training with heavy loading vs. repetitions to failure. *J Strength Cond Res* 26: 1897–1903, 2012.
32. Tarnanen, S, Neva, MH, Häkkinen, K, Kankaanpää, M, Ylinen, J, Kraemer, WJ, Newton, RU, and Häkkinen, A. Neutral spine control exercises in rehabilitation after lumbar spine fusion. *J Strength Cond Res* 28: 2018–2025, 2014.
33. Youdas, JW, Budach, BD, Ellerbusch, JV, Stucky, CM, Wait, KR, and Hollman, JH. Comparison of muscle-activation patterns during the conventional push-up and perfect pushup™ exercises. *J Strength Cond Res* 24: 3352–3362, 2010.