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Research article

Push-Ups vs. Bench Press Differences in Repetitions and Muscle Activation between Sexes

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Abstract

Push-ups are an ubiquitous resistance training exercise. While exhibiting a relatively similar upper body motion to the bench press, there are substantial differences in repetitions when employing similar relative loads. The objective was to examine sex-related differences in repetitions and muscle activation associated with push-ups and bench press exercises. Twenty resistance-trained participants (10 men [22 ± 6.1 years] and 10 [24 ± 5.7 years] women) performed maximum push-up and bench press repetitions with loads relative to the body mass during a push-up. Electromyographic (EMG) electrodes were positioned on the middle and anterior deltoids, triceps and biceps brachii, and pectoralis major muscles and their relative (normalized to a maximum voluntary contraction) activity was compared between the two exercises performed to task failure. Both females (3.5 ± 3.9 vs.15.5 ± 8.0 repetitions; $p = 0.0008$) and males (12.0 ± 6.3 vs. 25.6 ± 5.2 repetitions; $p < 0.0001$) performed 77.4% and 53.1% less bench press than push-up repetitions respectively. Males significantly exceeded females with both push-ups ($p = 0.01$) and bench press ($p = 0.004$) repetitions. Significant linear regression equations were found for females ($r^2 = 0.55$; $p = 0.03$), and males ($r^2 = 0.66$; $p < 0.0001$) indicating that bench press repetitions increased 0.36 and 0.97 for each push-up repetition for females and males respectively. Triceps ($p = 0.002$) and biceps brachii ($p = 0.03$) EMG mean amplitude was significantly lower during the push-up concentric phase, while the anterior deltoid ($p = 0.03$) exhibited less activity during the bench press eccentric phase. The sex disparity in repetitions during these exercises indicates that a push-up provides a greater challenge for women than men and regression equations may be helpful for both sexes when formulating training programs.

Key words: Electromyography; muscle endurance; resistance training; females; gender.

Introduction

Bench press and push-ups are two ubiquitous resistance exercises with a primary objective to strengthen the upper body. In addition, these two exercises are often used to assess upper body muscular strength and endurance. The bench press is an open kinetic chain movement while push-ups are a closed kinetic chain movement that are deemed biomechanically comparable to each other (both involve shoulder horizontal flexion and extension and elbow flexion and extension) (Blackard et al., 1999; Dillman et al., 1994; van den Tillaar and Saeterbakken, 2014). However, when the bench press load is matched to the push-up load, the number of repetitions performed to failure is much higher for the push-up exercise versus the bench press. Amasay et al. (2016) recently reported a greater number of push-ups (33 vs. 30 push-ups) performed than bench press (25 vs. 6 repetitions) when the load was matched to the body mass during a push-up for both men and women, respectively. However, in their study, women performed modified push-ups (fulcrum point at the knees rather than the toes) and there was no measure of neuromuscular activation to help identify the different mechanisms regarding the exercises and sex factors. Clemons et al. (2019) also examined push-up performance but only with young men (n=31; 20.2±2.1 years), using multiple regression analysis to determine bench press one repetition maximum (1RM) from the maximum push-ups repetitions. Since push-ups are relatively safe and stable with little coordination needed to perform them and do not need specialized equipment, they should be an ideal exercise for which to predict upper body training loads such as with the bench press. Since the bench press barbell has greater instability creating a need for greater coordination, predicting bench press training requirements for each sex from this simple exercise would be very advantageous to both the fitness professional and enthusiast.

There must be other contrasts between the exercises such as differences in neuromuscular activation that contribute to the disparity in repetitions. Calatayud et al. (2015) reported that the push-ups and bench press can be used interchangeably for strength gains in terms of neuromuscular activation. Similarly, pectoralis major, anterior deltoid, biceps brachii, and triceps brachii electromyographic (EMG) activity were similar between bench press and push-up variations (Gottschall et al., 2018). In contrast, Danielsson (2017) showed higher pectoralis major muscle activation when averaging five repetitions of the bench press (64% of body mass), versus five push-ups at a rate of 40 bpm. Comparably, a systematic review concluded that with the bench press, the EMG activity of the pectoralis major and triceps brachii were similar but both muscles were higher compared to the activity of the anterior deltoid due to their muscular size and force production ability (Stastny et al., 2017).

Perhaps there are a greater variety of EMG differences between push-up and bench press muscle activation (i.e. EMG amplitude, median frequency, timing pattern) than just overall EMG activity. For example, pectoralis major, anterior deltoid and triceps brachii EMG activity increased during the ascending phase (concentric) of a bench press, while the EMG activity of the pectoralis major and anterior deltoid increased during the descending

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(eccentric) phase with a 6-repetition maximum (van den Tillaar and Saeterbakken, 2014). One underlying principle of fatigue is its task dependency (Enoka and Stuart, 1992). With fatigue, pectoralis major, triceps brachii, and anterior deltoid activation increased while maintaining movement pace during a bench press (Sakamoto and Sinclair, 2012). Brennecke et al. (2009) found when an induced fatigue protocol was introduced, only the pectoralis major increased muscular activity during the tonic (stabilizing) phase of bench press. However, there are no studies that have examined changes in associated muscle activity with push-ups to fatigue. The limited number of repetitions (1-6 repetitions) used in prior research (Calatayud et al., 2015; Gottschall et al., 2018) may not have accentuated any possible differences between push-ups and bench press. The greater stresses associated with fatigue may better delineate neuromuscular activation and task differences (i.e. trunk stabilization with push-ups, barbell instability with bench press, excursion of the bench press barbell versus body mass with push-ups) between push-ups and bench press.

When performing push-ups, women experienced near significantly higher pectoralis major ($p = 0.06$) and triceps brachii ($p = 0.17$) EMG activity and higher triceps brachii EMG variability than men (Cogley et al., 2005). In bench press, females demonstrated higher pectoralis major, anterior deltoid muscle activity compared to men while performing 55%, 70%, 85%, and 100% of one maximum repetition. However, unlike push-ups, men demonstrated a higher triceps activity compared to women in the bench press (Gołaś et al., 2018). With the scant research examining sex differences in these two ubiquitous resistance exercises, more studies are necessary.

Thus, the objective of this study was to examine differences in the number of repetitions performed and EMG activity of associated muscles (pectoralis major, anterior and medial deltoid, triceps brachii and biceps brachii) between load matched bench press and push-ups in young adult men and women. A second objective was to provide regression equations to predict the appropriate number of bench press repetitions from testing of push-up repetitions. It was hypothesized that a greater number of repetitions would be executed with push-ups while higher muscle activation would be observed during the load matched bench press. Secondly, based on the greater upper body muscle mass and strength of men, it was hypothesized that men would exceed women with both push-up and load matched bench press repetitions.

Methods

Experimental Design

This was a quasi-experimental design study. Ten men and 10 women performed maximum push-up and bench press repetitions with loads relative to the push-up resistance. Electromyographic (EMG) electrodes were positioned on the middle and anterior deltoids, triceps and biceps brachii, and pectoralis major muscles and their relative (normalized to an isometric bench press maximum voluntary contraction) activity was compared between the two exercises performed to task failure (maximum number of repetitions). Correlation coefficients and equations were derived to predict the number of bench press repetitions performed from maximum push-up repetitions.

Participants

Based on changes in maximum repetition numbers as well as EMG measures from anterior deltoid, pectoralis major, biceps brachii, and triceps brachii from previous studies (Amasay et al., 2016; Gottschall et al., 2018), a priori statistical power analysis was conducted. It was determined that a sample size of 3-6 (calculation predictions based on number of repetitions) and 6-26 (calculation predictions from the four monitored muscles) were needed to achieve an alpha of 0.05 and a power of 0.8. The average sample size number from the EMG measures was then calculated ($n = 14$); hence, 20 participants (males = 10: 22 ± 6.1 years, 1.78 ± 0.34 m, 81.4 ± 9.8 kg; female s= 10: 24 ± 5.7 years, 1.60 ± 0.59 m, 62.5 ± 7.7 kg;) were recruited through convenience sampling. Participant inclusion criteria included healthy individuals, 18-30 years with resistance training experience (averaged ≥2 resistance training sessions per week over the prior 6 months). Exclusion criteria included participants with upper body musculoskeletal injuries within the prior 6 months. Participants were informed that no stimulants (i.e. caffeine, nicotine or others) were to be ingested at least 6 hours prior to testing. Fluid intake was permitted ad libitum. After familiarizing the participants with the general scope of the study, they read and signed a consent form. The study was approved from the local ethical committee (ID:HKR20200042).

Push-up test (calculation of the load for the bench press)

Two Taylor® (model: 7410BL, Taylor Precision Products, Inc., Las Cruces, NM, USA) scales were placed at shoulder width (thumbs directly under the acromioclavicular joint) for the push-up position. The digital scales were calibrated with weights to a load cell (S-beam load cell, model number LC101-500, Omegadyne, Inc., Sunbury, OH, USA). Based on this shoulder width and the same positioning of hands upon the scales (distance from border of scales measured and noted), the distance from the hypothenar eminence of one hand to the other was measured to reproduce the hand position in subsequent tests. Participants took a push-up position with their elbows fully extended (up position) and their knees off the ground while the mass on each scale was recorded for each hand. Next the participants took the push-up position with their elbows flexed at 90^0 (upper arms/triceps brachii parallel to the floor) while maintaining a straight trunk (no concavity or convexity of the back or trunk) and their knees off the ground. Similarly, the mass produced by each hand in this position was recorded. The average sum of the masses, exerted during both up and down push-up position, was calculated to be recreated on barbell bench press test (Gottschall et al., 2018).

EMG Activity

Using a similar protocol employed in past publications from this laboratory (Anderson and Behm 2004; Behm et al. 2002), the EMG activity of five muscles (i.e. pectoral major, anterior deltoid, medial deltoid, triceps brachii lateral head, and biceps brachii) was recorded using surface EMG (EMG 100c, Biopac Systems, QC, Canada), at a sampling rate of 2000 Hz, amplified (bi-polar differential amplifier, input impedance of 2 MOhms, common mode rejection ratio of 110 dB min (50/60 Hz), gain of 1000, noise of ±0.05 mV), and a Blackman analog low band-pass filter with cut-off frequencies at 500Hz. Single-use silver/silver chloride bipolar surface electrodes (1-cm Ag/AgCl; MediTrace Covidien 130 Foam, Kendall, ON, Canada) with an inter-electrode distance of 2 cm were placed 10cm below the clavicle and 5cm distal from the sternum for the pectoral major. Half the distance from the acromion to the deltoid insertion was calculated for anterior and medial deltoid. The anterior deltoid electrodes were placed anteriorly relative to the insertion of the deltoid. Electrodes were placed at the half way point from the acromion to the olecranon process of ulna for the triceps brachii lateral head. Fifty percent of the distance between the acromion process and the radial notch was the electrode placement location of the biceps brachii. The ground electrode was placed on the clavicle. Prior to the attachment of the electrodes, hair was shaved using a disposable razorblade, the skin abraded using a fine sandpaper and cleaned using alcohol swabs. The electrodes were then secured in place with medical tape.

All analog data were digitized using a 12-bit A/D board (Biopac Systems Inc., DA 150: analog-digital converter MP150WSW; Holliston, Massachusetts) and stored on a computer running AcqKnowledge 4.1 Software (Biopac Systems Inc., Holliston, Massachusetts). EMG data were processed using a Blackman finite impulse response dB band-pass filter from 10Hz to 500Hz and later smoothed with a linear envelope at a sample factor of 10 (Anderson and Behm, 2004), and then the root-mean-square (RMS) was calculated (Konrad, 2005). EMG values were normalized to the MVC. In order to compare to relative EMG activity of each muscle between individuals, (since each individual performed different number of repetitions), EMG activity during the fatiguing protocols (number of repetitions of push-up and bench press to task failure) were divided into quartiles. Since some individuals could only perform a single load matched bench press, the first repetition was also included in the analysis (i.e. repetition 1, quartiles 1-4).

Procedure

Upon arrival in the lab the participants were asked to fill out a physical activity readiness questionnaire (PAR-Q+) to determine if they were eligible to be included in the study. Then participants filled out a personal information form as well as determining their level of physical activity. After taking their height and weight, the mass produced by each arm was recorded using two scales in both up and down push-up positions as well as the distance between the hands using a tape measure. Next, electrodes were attached according to the aforementioned placements. The average baseline signal noise was assessed from a point-to-point range while the participants were told to relax their muscles followed by a subsequent forceful contraction to ensure that electrode placements were accurate. Baseline noise above 0.05mv were considered high and electrode placement procedure was repeated again for that specific muscle. Next the participant warmed up using an arm ergometer (Monark Rehab Trainer ™ 881E; Monark Bodyguard, Quebec, Canada) for 3 minutes at 60rmp.

The load cell (S-beam hanging load cells, model number LC101-500, Omegadyne, Inc., Sunbury, OH, USA) was calibrated prior to each measurement at a sampling rate of 20kHz. Afterwards, the participants proceeded to have their bench press isometric force measured using the load cell. Three submaximal isometric contractions were performed followed by a 1-minute rest. Participants were asked to perform two maximum isometric contraction of the bench press with upper arms parallel to the floor and elbows flexed at 90^0. If the difference of the force generated between the two trials were more than 5% then a third attempt was completed. The maximum isometric bench press was performed in order to normalize and compare the relative EMG activity from the push-ups and load matched (to push-up mass) bench press.

Push-up and bench press tests were recorded on two separate sessions at the same time of day to avoid diurnal variations with each session completing all the previous steps. In the push-up session, the participant was asked to perform the maximum number of push-ups possible while adhering to a metronome pace of 60 bpm (1 second up and 1 second down) (Eckel et al., 2017; Kim et al., 2002). Hand position was maintained from test to test based on the recorded distance of the hypothenar from the border of the scale and the recorded distance between the hands. The concentric and eccentric phase of the push-up was determined visually by creating an event each time the participant was in either the up position, with the elbows fully extended, or down position in the push-up.

For the bench press, the hand position used for the push-up trial was marked on the Olympic style barbell (length: 2 metres). The resistance of the bench press was load matched with the average mass calculated from the push-up session. Similar to the push-up the participants were asked to perform the maximum number of repetitions possible while adhering to a metronome pace of 60bpm. The concentric and eccentric phases were also determined visually by creating events during the EMG recording.

Statistical analyses

Statistical analyses were completed using the SPSS software (Version 26.0, IBM Corp., Armonk, NY). The assumptions of sphericity and normality were tested for all dependent variables and if a violation was noted, the corrected values for non-sphericity with Greenhouse-Geisser were reported. With the analysis of exercise repetitions, a two-way mixed-model ANOVA with repeated measures on the exercise factor was used to analyze the factors of sex (2), and exercises (2: push-ups and bench press). Pearson correlation coefficients and linear regression equations were used to calculate the association between bench press and push-up repetitions and to predict the number of push-ups or bench press repetitions that can be performed based on the performance of the other variable (i.e. predicting the number of bench press repetitions from the number of push-ups performed) respectively. Concentric and eccentric EMG activity was analyzed separately with three-way mixed model ANOVAs with repeated measures on the exercise and time factors was used to analyze the factors of sex (2), exercises (2: push-ups and bench press) and time (5: repetition #1, first, second, third and fourth quartiles) in each dependent variable (pectoralis major, anterior and middle deltoid, triceps and biceps brachii EMG). For the participants who were unable to complete more than one bench press or push-up, only the first repetition was included in analysis. Relative push-up force exerted in relation to body mass (%) were analyzed using a two-way repeated measures ANOVA with the push-up position (up and down) as a within subject factor and gender as between subject factor. In the event of significant main effects or interactions, planned pairwise comparisons were made using the Bonferroni method to test for differences among mean value time points. The level of significance was set at $p < 0.05$ and all results are expressed as mean ± SD. Effect size (d) magnitude of change were calculated for interactions and reported as trivial (<0.2), small (0.2-0.49), medium (0.5-0.79) or large (≥0.8) effect sizes (d) (Cohen, 2013). Furthermore, eta^2 measures indicating the magnitude of changes associated with significant main effects were provided and reported as small (<0.01), medium (≥0.06) or large (≥0.14).

Results

Push-ups mass at different positions

A significant main effect for push-up position was found ($F_{(2,17)} = 16.77$; $p < 0.0001$; $eta^2 = 0.66$). The amount of mass exerted in the down position (72% of body mass) during push-up was 9% higher compared to the up position (66% body mass). No main effect was found for gender or push-up position*sex interaction for relative body mass (relative proportion of body mas supported by the arms). Males displayed significantly ($F_{(2,17)} = 22.4$; $p < 0.0001$; $eta^2 = 0.98$) higher absolute body mass for the up (53.4 ± 8.5 vs. 44.5 ± 5.9 kg), down (59.2 ± 9.9 vs. 47.7 ± 7.6 kg) positions of the push-up as well as total body mass (80.9 ± 11.9 vs. 66.6 ± 8.4 kg).

Push-ups versus bench press repetitions

Between sex comparisons of repetitions (both push-up and bench press combined) ($F_{(1,14)} = 90.8$; $p < 0.007$; $eta^2 = 0.41$) showed that males significantly exceeded females by 49.4% (d = 1.5) (Table 1). Post-hoc interactions revealed that females ($p = 0.0008$) and males ($p < 0.0001$) performed 77.4% (d = 1.7) and 53.1% (d = 2.4) less bench press than push-ups repetitions respectively (Table 1). Males significantly exceeded females with both push-ups ($p = 0.01$; d = 1.5) and bench press ($p = 0.004$; d = 1.6) repetitions (Table 1). A significant main effect for exercise ($F_{(1,14)} = 98.3$; $p < 0.0001$; $eta^2 = 0.87$) indicated that participants (male and female combined) performed 62.3% (d = 1.6) less bench press than push-up repetitions (Table 1).

Pearson correlation coefficients showed strong associations between the number of repetitions performed with push-ups and bench press for females ($r = 0.74$), males ($r = 0.81$) and with both sexes combined ($r = 0.81$). A significant regression equation was found ($F_{(1,6)} = 7.49$, $p = 0.03$), with an r^2 of 0.55 for females, and ($F_{(1,14)} = 27.77$ $p < 0.0001$), with an r^2 of 0.66 for males. Females' predicted number of bench press repetitions (with similar resistance as experienced during a push-up) was equal to -2.117 + 0.362 (push-up repetitions) repetitions. The number of bench press repetitions increased 0.362 for each repetition of push-up for females (Figure 1, top). Males' predicted number of bench press repetitions (with similar resistance as experienced during a push-up) was equal to -12.94 + 0.973 (push-up repetitions) repetitions (Figure 1, bottom). The number of bench press repetitions increased 0.973 for each repetition of push-up for males.

Bench press versus push-ups exercise EMG activity comparisons

The only significant interaction ($F_{(4,32)} = 2.9$; $p = 0.036$; $eta^2 = 0.26$) demonstrated a lower normalized EMG activity of the middle deltoid during the fourth quartile with the concentric phase of the push-ups (11.1 7.8%) versus bench press (17.7 ± 2.7%). Main effects for exercise (Table 2) illustrated lower triceps ($F_{(1,8)} = 20.18$; $p = 0.002$; $eta^2 = 0.71$) and biceps brachii ($F_{(1,8)} = 6.34$; $p = 0.036$; $eta^2 = 0.44$) normalized EMG activity when performing the concentric phase of push-ups versus bench press respectively. With the eccentric phase, a main effect for exercise ($F_{(1,8)} = 6.72$; $p = 0.032$; $eta^2 = 0.45$) indicated lower normalized EMG activity during the bench press versus the push-up for the anterior deltoid.

Table 2. Mean normalized (to bench press MVC) EMG activity.

	Push-ups	Bench press
Triceps Brachii Concentric Phase	7.9% ± 4.9% *	11.9% ± 3.9%
Biceps Brachii Concentric Phase	9.4% ± 2.9% *	16.4% ± 10.1%
Anterior Deltoid Eccentric Phase	11.0% ± 3.6%	7.1% ± 2.6% #

* illustrate that EMG activity was significantly ($p < 0.05$) lower during the concentric phase of the push-ups versus the bench press. # represents a significant difference between the anterior deltoid activity during the eccentric phase of bench press and push-up repetitions.

Table 1. Push-ups versus bench press repetitions (n).

	Bench press repetitions	Push-up repetitions	Combined Means of Bench press and Push-ups
Males	12.0 ± 6.3 *	25.6 ± 5.2 *	18.8 ± 6.15 *
Females	3.5 ± 3.9	15.5 ± 8.0	9.5 ± 6.3
Combined Means of Male and Female values	7.75 ± 6.9	20.5 ± 8.7 #	

* illustrate that males significantly ($p < 0.05$) exceeded female repetitions. # represents a significant ($p < 0.05$) difference between bench press and push-up repetitions.

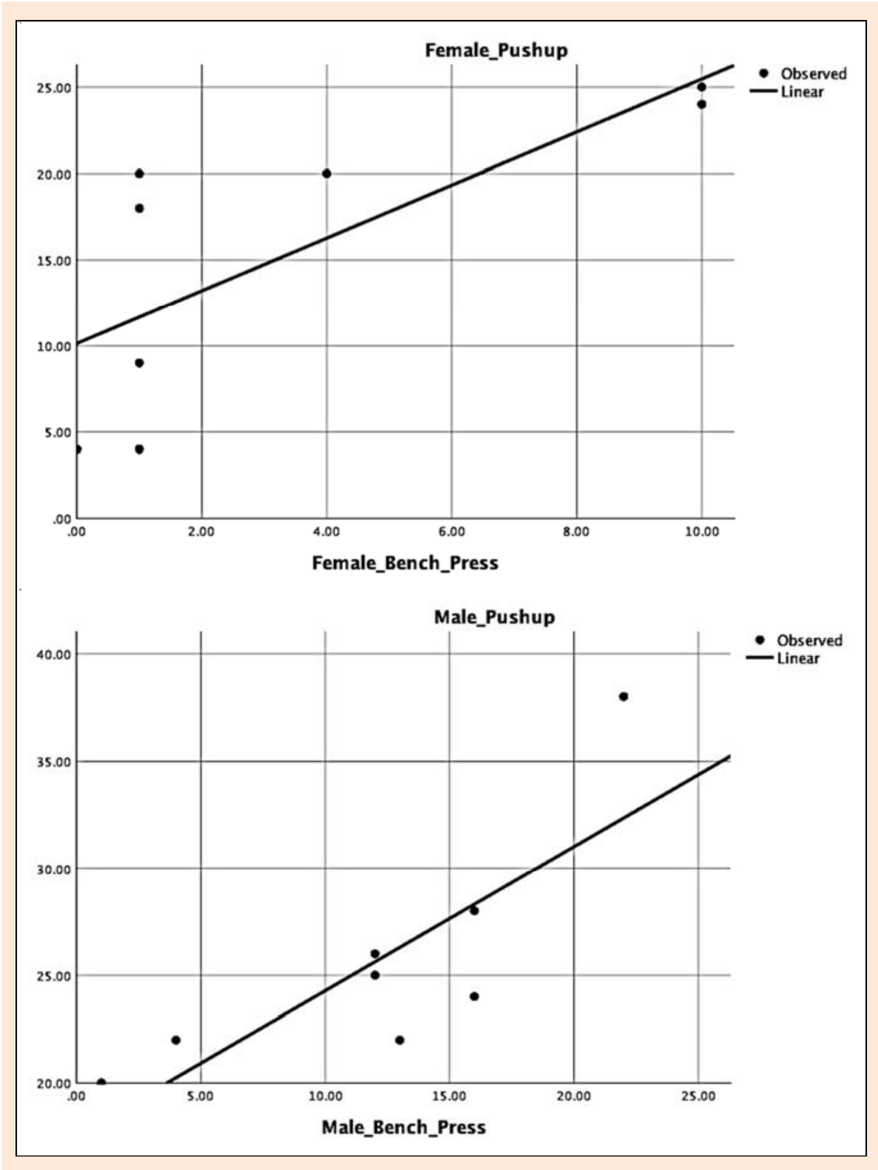

Figure 1. **Top: Linear regression between female push-ups (y axis) and bench press (x axis) repetitions.**
Bottom: Linear regression between male push-ups (y axis) and bench press (x axis) repetitions.

EMG Sex Differences

Main effects for sex were evident with lower male normalized EMG activity with the pectoralis major, and triceps brachii when performing the concentric bench press, triceps and biceps brachii when performing concentric push-ups, anterior deltoid with the eccentric bench press and the pectoralis major, anterior deltoid and triceps brachii when performing an eccentric push-up. All statistical details are provided in Table 2.

EMG Activity with Repeated Repetitions

Main effects for time illustrated that EMG activity from the first repetition generally increased in subsequent repetition quartiles (Table 3). The pectoralis major EMG activity increased with the concentric bench press and eccentric push-ups, whereas anterior deltoid EMG increased with the eccentric bench press and concentric push-ups. While the triceps brachii increased EMG activity with the concentric and eccentric phases of the bench press and push-ups, the biceps brachii only increased EMG activity with concentric push-ups. More statistical details are provided in Table 4.

Discussion

The main findings were that overall (males and females combined), less repetitions were completed with the bench press when adjusted for the weight exerted during push-ups, and secondly, male participants completed a higher number of repetitions in both bench press and push-ups compared to females. A strong correlation was observed between the number of bench press and push-up repetitions. Triceps and biceps brachii demonstrated a lower extent of muscular activity during the concentric phase of the push-up compared to the concentric phase of the bench press. The anterior deltoid also showed a lower amount of muscular activity during the eccentric phase of the bench

Table 3. Mean normalized (to MVC) EMG sex differences with a single contraction.

	Muscle	Female EMG	Male EMG	F scores	p value	eta^2
			Concentric			
Bench press	Pectoralis Major	19.9%	14.4%	$F_{(1,7)}=5.46$	p=0.05	0.438
	Triceps	17.9%	11.5%	$F_{(1,7)}=4.41$	p=0.07	0.387
Push-ups	Triceps	20.1%	10.3%	$F_{(1,15)}=9.58$	p=0.007	0.390
	Biceps	14.6%	8.8%	$F_{(1,15)}=7.11$	p=0.018	0.322
			Eccentric			
Bench press	Anterior Deltoid	9.1%	6.5%	$F_{(1,8)}=2.76$	p=0.10	0.257
Push-ups	Pectoralis Major	2.5%	1.9%	$F_{(1,14)}=3.92$	p=0.068	0.219
	Anterior Deltoid	13.6%	9.7%	$F_{(1,14)}$ 2.32	p=0.10	0.142
	Triceps	12.0%	6.2%	$F_{(1,14)}=7.0$	p=0.019	0.334

Table 4. EMG main effects for time.

	Concentric Bench Press	Concentric Push-Ups	Eccentric Bench Press	Eccentric Push-ups
Pectoralis Major	Rep1>Q4, p=0.08 Q4>Q2, p=0.03	N/S	N/S	Q4>Rep1, p=0.05 Q3>Q1, p=0.05 Q4>Q1, p=0.014 Q4>Q2 p=0.011
Anterior Deltoid	N/S	Q2>Rep1, p=0.03 Q3>Rep1, p=0.001 Q2>Q1, p=0.01 Q3>Q1, p=0.004	N/S	Q4>Rep1, p=0.008 Q3>Q1, p=0.06 Q4>Q1, p=0.07 Q4>Q2, p=0.08
Middle Deltoid	N/S	N/S	N/S	N/S
Triceps Brachii	Q2>Rep1, p=0.08 Q3>Rep1, p=0.06	Q1>Rep1, p=0.02 Q2>Rep1, p=0.002 Q3>Rep1, p<0.0001 Q4>Rep1, p=0.001 Q3>Q1, p<0.0001 Q3>Q2, p=0.08	Q2>Q1, p=0.048	Q4>Rep1, p=0.05 Q3>Q1, p=0.05 Q4>Q1, p=0.10
Biceps Brachii	N/S	Q1>Rep1, p=0.03 Q2>Rep1, p=0.06	N/S	N/S

Q: quartile, Rep: repetition, N/S: non-significant

press compared to the eccentric phase of the push-up. Generally, males had a lower amount of muscular activity compared to females in both exercises. The amount of muscle activity also increased with the number of repetitions.

The greater repetitions with push-ups than bench press are in accord with prior research (Amasay et al., 2016). From a biomechanical standpoint, this finding can be justified. The vertical distance of the center of mass traveled when performing a bench press is higher compared to push-ups. The center of mass for a human body is located at 41.2% of their height, which would be roughly close to the mid-section of the human body (Clauser et al., 1969). Although the movement in the shoulder joint between push-up and bench press may be similar (van den Tillaar and Saeterbakken, 2014), the center of mass load displacement is quite different.

In a sagittal view, the push-up is considered to be a second-class lever whereas, the bench press when ascending the bar, would progress towards a third-class lever as the bar moves towards the bench relative to the shoulder joint (Duffey and Challis, 2007; Elliott et al., 1989; Madsen and McLaughlin, 1984). Eckel et al. (2017) found similar results showing that more repetitions were performed with push-ups compared to bench press. They argued that higher core activation during push-ups is correlated with the higher repetitions performed during push-ups. Body position was another factor discussed by Eckel et al. (2017). The changes in the centre of mass position during push-up from the up position to down position may be a primary reason higher repetitions are performed during push-ups. It is suggested that push-ups are more similar to a decline bench press leading to a shorter moment arm and limited range of motion (Eckel et al., 2017). Due to the changes in moment arm flexion during a push-up, the amount of mass that has to be supported would change from 69% in the up position to 75% in the down position (Contreras et al., 2012). These changes were also similar to the results of this study where the participants supported 66% of their body mass in the top position compared to 72% in the down position.

The stability of the exercise mode has been proposed as another factor contributing to differences in push-ups vs. bench press repetitions. During the push-up, force is exerted upon a stable surface, whereas in a bench press the barbell is freely moving and thus unstable (Chou et al., 2012) increasing the demand to stabilize and reduce the movement of the barbell (Amasay et al., 2016). Stability challenges are greater with the Olympic bar as any perturbation movements lead to greater disruptive torques due to the length of the barbell, which must be stabilized by the associated musculature. Closed chain exercises like push-ups are characterized by inducing an axial compressive load on the glenohumeral joint and functionally stabilizing it. This stabilization is achieved through the rotator interval structure, which mainly consists of ligaments as well as the biceps brachii tendon encapsulating the glenohumeral joint and the shoulder joint capsule (Yamamoto et al., 2006), thus reducing the energy expenditure. However, when performing an open chain exercise such as bench press, the stabilization of the shoulder is mainly achieved through activation of the surrounding muscles of both scapular and glenohumeral joint (Lephart and Henry, 1996). The deltoids and serratus anterior along with the upper trapezius function to stabilize the scapular and shoulder joint. These muscles have illustrated a higher activation in bench press compared to push-ups (Calatayud et al., 2014), which would increase the energy expenditure resulting in premature fatigue. For example, the increased middle deltoid EMG activity in the fourth quartile would be ascribed to increased motor unit recruitment and rate coding to compensate for fatiguing motor units (Behm, 2004). Increased muscle activation would also contribute to greater stabilization (Ostrowski et al., 2017) of a fatigue-induced unstable joint (Behm and Anderson, 2006).

Our results also showed that males generally demonstrated a higher number of repetitions in both push-ups and bench press compared to females, which is in accord with previous research (Amasay et al., 2016). In contrast, Clemons et al. (2019) reported similar push-up repetitions between men and women. However, the women in that study performed modified push-ups with their knees as the pivot point. The justification for this discrepancy has been suggested to be correlated to the upper-body relative strength difference between men and women (Bishop et al., 1987). The mean percentage difference for upper-body strength between men and women ranges from 75%-116% with males demonstrating higher amount of upper-body strength compared to women (Bishop et al., 1987), which may explain the difference in the amount of repetitions performed for men and women. Clemons et al. (2019) reported a strong association ($r=0.71$; $p=0.0001$) between push-up repetition number and relative strength (bench press 1RM as a percentage of body mass). Furthermore, males are generally more accustomed to push-up training with their toes or feet as the fulcrum point, whereas females are more familiar with doing the modified variation of push-up from the knees. Hence, male participants exhibited lower muscle activity and thus indicative of why push-ups are a less taxing activity for males compared to females.

Calatayud et al. (2015) did not find any difference in muscle activity of the pectoralis major and anterior deltoid between bench press and push-up. However, the purpose of their study did not involve a fatigue protocol. Furthermore, the intensity was not equated to the participant's push-up mass, rather they incorporated elastic bands to increase the load so the amount of repetitions both in bench press and push-ups would be similar. The results of this study show a lower anterior deltoid activity during the eccentric phase of bench press, which is similar to the previous report. It was found that the triceps brachii and biceps brachii demonstrated lower muscular activity during the concentric phase of the push-up compared to the concentric phase of the bench press. When a muscle experiences greater stress or is fatigued to a greater extent it must increase recruitment and rate coding to maintain or sustain the task. Since push-ups illustrated lower EMG activity, the demands on the muscle must have been less, allowing a lower extent of muscle activation to achieve the goal. Hence, less muscle activation could conserve energy and contribute to less fatigue and more repetitions. A non-significant similar finding can be seen in research by Gottschall et al. (2018) where they compared the EMG activity of different muscles in bench press vs. push-ups. However, the anterior deltoid in this study elicited a lower EMG activity during bench press whereas higher EMG activity was detected for the bench press compared to push-up in a previous study (Gottschall et al., 2018).

During the bench press, the participants showed less neuromuscular activity in the anterior deltoids compared to the push-up. Similar, although non-significant, differences were observed in a previous study (Calatayud et al., 2015). This result was also comparable to another study, which did not find significant differences in anterior deltoid activity between bench press and push-up, although it displayed relatively higher activity during the push-up (van den Tillaar and Saeterbakken, 2014). This is in contrast to the findings presented by Dillman et al. (1994) who found higher anterior deltoid activity during the bench press. One important factor to consider is the speed of the movement, which influences the amount of muscle activation (Sakamoto and Sinclair, 2012). The previous studies did not report on the speed of the movement whereas the movement speed considered for this study was considered to be faster compared to prior studies (Hsu et al., 2011; Sakamoto and Sinclair, 2012). Sakamoto and Sinclair (2012) for example had participants perform their bench press at 0.5 rep/sec compared to 1 second concentric and eccentric durations respectively in the present study.

Although most results demonstrated large effect sizes, as with many studies, a limitation of this study might be the moderate sample population of 10 men and 10 women. A greater number of data points could have provided more rigorous regression values. Furthermore, the results would only apply to resistance trained individuals as it was found that untrained women typically could not complete a single bench press repetition in this study and thus had to be excluded. Fat mass and fat free mass were not analyzed and could again have provided more precise interpretations. However, all participants were trained individuals with no male or female participant exhibiting excessive fat mass. Future studies could attempt to evaluate a wider scope of the population as well as analyze the kinematics in combination with the EMG.

In conclusion, greater push-up repetitions were completed compared with a similar load bench press. Lower male EMG activity during the exercises representing lower stress or relative load on the muscle potentially contributed to their higher repetitions in both bench press and push-ups compared to women. A strong correlation between the number of bench press and push-up repetitions permitted a formulation of a regression equation to predict the number of bench press repetitions from push-up performance. Triceps and biceps brachii demonstrated a lower muscular activity during the concentric phase of the push-up compared to the bench press, while the anterior deltoid also exhibited less activity during the eccentric phase of the bench press compared to the push-up.

Conclusion

The present study provides a practical calculation for the number of bench press repetitions that can be performed from push-up repetition performance. This can help with the formulation of training programs especially with more novice individuals of both sexes. Since there is greater stability, no chance of injury from erratic movements of dumbbells or barbells and very little motor learning involved with push-ups, push-ups are an excellent exercise to use to gauge and predict the initial loads to be implemented when progressing to a bench press exercise. The sex disparity in repetitions and muscle activation during these exercises indicates that push-ups may provide a greater training stress to women than men and may be a good starting point when initiating a resistance training program.

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Key points

- Greater push-up repetitions were completed than with a similar load bench press.
- Men had less EMG activity during the exercises potentially contributing to their higher repetitions in both bench press and push-ups compared to women
- Based on the strong correlation between bench press and push-up repetitions a regression equation was calculated to predict the bench press repetitions from push-up performance. The regression equation can aid in developing training programs
- Push-ups may provide a greater training stress to women than men and provide an excellent starting point when initiating a resistance training program.

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