

Effect of Push-up Speed on Upper Extremity Training until Fatigue

Hsiu-Hao Hsu¹ You-Li Chou² Yen-Po Huang¹

Ming-Jer Huang^{1,3} Shu-Zon Lou⁴ Paul Pei-Hsi Chou^{5,6,7,*}

¹Department of Engineering Science, National Cheng-Kung University, Tainan 701, Taiwan, ROC

²Institute of Biomedical Engineering, National Cheng-Kung University, Tainan 701, Taiwan, ROC

³Department of Logistics and Technology Management, Leader University, Tainan 709, Taiwan, ROC

⁴School of Occupational Therapy, Chung Shan Medical University, Taichung 402, Taiwan, ROC

⁵Faculty of Sports Medicine, Kaohsiung Medical University, Kaohsiung 807, Taiwan, ROC

⁶Department of Orthopedic Surgery, Kaohsiung Medical University Hospital, Kaohsiung 807, Taiwan, ROC

⁷Department of Orthopedic Surgery, Kaohsiung Municipal Hsiao-Kang Hospital, Kaohsiung 812, Taiwan, ROC

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Abstract

Push-up exercises are commonly performed to strengthen the upper extremity muscles. However, the relationship between the push-up speed and upper extremity fatigue is not well understood. Accordingly, the present study investigated the effect of the push-up speed on the maximum possible number of push-up repetitions until fatigue and the upper-extremity muscle activity, respectively, in order to identify suitable push-up strategies for upper-extremity muscular strengthening. Fifteen healthy males participated in the study. Each subject performed push-ups at three different speeds (i.e., fast: 7 push-ups/10 s; regular: 5 push-ups/10 s; and slow: 4 push-ups/10 s) until fatigued. The muscle activity signals were measured during the push-up tests via surface electromyography. The strengthening effect of the push-up exercises was evaluated by measuring the myodynamic decline rate at the shoulder, elbow and wrist joints using an isokinetic dynamometer. The results showed that the maximum possible number of push-up repetitions at the fast push-up speed was around 1.34 and 1.33 times higher than that at the regular push-up speed or slow push-up speed, respectively. However, the endurance time (i.e., the time to fatigue) at the slow push-up speed was around 1.20 and 1.24 times longer than that at the fast push-up speed or regular push-up speed, respectively. Finally, at the slow push-up speed, the total muscle activations in the triceps brachii, biceps brachii, anterior deltoid, pectoralis major, and posterior deltoid, respectively, were 1.47, 2.43, 1.42, 1.48, and 1.91 times higher than those at the fast push-up speed. Therefore, the experimental results suggest that push-ups should be performed at a faster speed when the aim is to achieve a certain number of repetitions, but should be performed at a slower speed when the aim is to strengthen the upper extremity muscles.

Keywords: Push-up, Upper extremity, Electromyography (EMG), Isokinetic dynamometer, Muscular strengthening

1. Introduction

Push-up exercises are convenient, easily learned, and readily adapted to various levels of difficulty. As a result, they are commonly performed by health-conscious individuals and athletes to strengthen the upper extremity muscles [1]. When performing upper extremity movements, stability of the joints is ensured not only by the surrounding tissue (e.g., the ligaments and capsules), but also by the muscular contraction strength. As a result, maintaining and improving the muscular

strength is essential in enhancing an individual's performance ability and preventing movement-related injuries. Of all the training exercises available for the upper extremity, push-ups are among the most common since they yield a notable improvement in both the muscle strength and the muscle endurance.

Many studies have established biomechanical kinematic and kinetic models of the upper extremity [2-6]. Furthermore, the effects of different types of push-ups on the degree of muscle activation have also been reported. For example, a narrow base position results in significantly higher electromyography (EMG) activities of the pectoralis major and triceps brachii muscle groups than a wide base position [7]. Similarly, the pectoralis major muscle activation in posterior

* Corresponding author: Paul Pei-Hsi Chou
Tel: 886-7-3208209; Fax: 886-7-3119544
E-mail: pc.arthroscopy@gmail.com

push-ups is higher than normal, whereas the triceps muscle activation is lower than normal [8]. However, the correlation between the push-up speed and the strengthening effect of push-up exercises is not yet clear. Therefore, the implications of the push-up speed on the muscular performance and the maximum possible number of repetitions are also not fully understood. Accordingly, this study investigated the effect of the push-up speed (fast, regular and slow) on the maximum possible number of repetitions, the endurance time, the upper-extremity muscle activation, and the myodynamic decline rate. The myodynamic decline rate in different isometric test conditions was measured using an isokinetic dynamometer and the muscle activity at different push-up speeds is measured via surface electromyography. The study provides an insight into the different usage mechanisms of the muscle groups when performing push-ups at different speeds and enables the identification of appropriate push-up strategies for upper extremity training.

2. Materials and methods

2.1 Participants and experimental protocol

Fifteen physically healthy male students participated in the investigation. The subjects ranged from 22 to 27 yrs of age (24.27 ± 1.22 yrs), 60 to 84 kg in weight (72.47 ± 5.93 kg), and 170 to 180 cm in height (174.67 ± 2.87 cm). The BMI of the participants ranged from 20 to 26 kg/m² (23.7 ± 1.8 kg/m²). All of the participants were right-hand dominant and free of upper-extremity disorders.

The effect of the push-up speed on the myodynamic (i.e., muscle strength) decline rate was examined by measuring the torque at the shoulder, elbow and wrist joints before and after the push-up exercises using an isokinetic dynamometer (Kin Com KC125AF, Kin Com Isokinetic International Corp., Harrison, TN). As shown in Fig. 1, each subject was asked to perform ten isometric tests, namely shoulder extension (SE), shoulder flexion (SF), shoulder abduction (SAB), shoulder adduction (SAD), shoulder external rotation (SRE), shoulder internal rotation (SRI), elbow extension (EE), elbow flexion (EF), forearm supination (FS) and forearm pronation (FP). In each case, the myodynamic decline rate was calculated as $(T_{pre} - T_{post})/T_{pre}$, where T_{pre} and T_{post} are the measured torque values before and after the push-up test, respectively.

The muscle activity signals at the different push-up speeds were measured using a surface electromyography (sEMG) system (MA300, Motion Analysis Corp.) at a sampling rate of 1000 Hz. For each subject, EMG sensors were attached to the supinator, pronator teres, triceps brachii, middle deltoid, biceps brachii, anterior deltoid, pectoralis major, posterior deltoid, infraspinatus and teres minor muscle groups [9,10]. Having attached the EMG electrodes, the subjects performed a series of 3-second maximum voluntary isometric contractions (MVIC) of the relative muscle group in order to obtain a datum with which to normalize the EMG data acquired during the push-up tests [10]. The raw sEMG data collected during the tests were exported to Matlab (Mathworks Inc., Natick, MA, USA) for

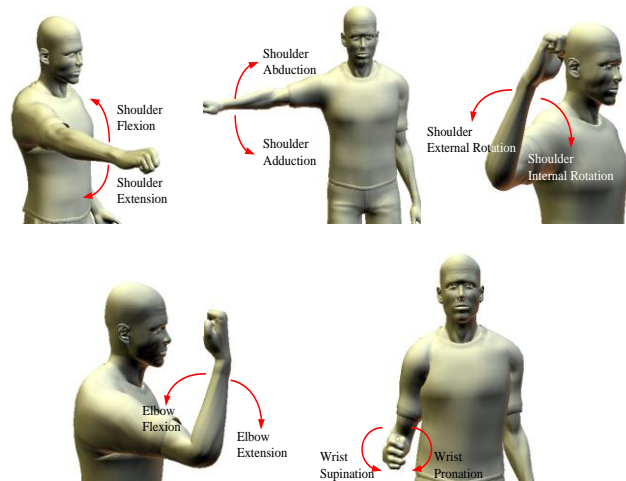


Figure 1. Isometric test conditions used to evaluate rate of myodynamic decline following push-up tests.

further analysis and processing. The data were initially rectified by converting the negative voltage signals to positive signals, and a linear envelope was then used to estimate the volume of the muscle activation. The sEMG data were divided by the corresponding MVIC value in order to obtain a normalized MVIC value (%MVIC) in the range 0~100% [10,11]. It should be noted that the actual muscle activation during the push-up exercises was determined from the vertical displacement history of a reflexive marker attached to the 4th thoracic vertebrae rather than from the EMG data. In addition, the duration over which the volume of muscle activation was evaluated in this study was defined as the total duration of the push-up test (i.e., from the start of the test until the point of fatigue). The total muscle activation (TMA) in each push-up test was computed as

$$TMA \{EMG(t)\} = \int_0^T \frac{EMG(t)}{MVIC} dt \times 100\% \quad (1)$$

where T is the total duration of the test.

Before starting the push-up tests, the subjects were asked to extend their elbows fully and to position both hands in a forearm axially non-rotated posture. The hand width was set to 1.5 times the shoulder width and the feet were set to one shoulder-width apart. The subjects were asked to perform push-ups at three different speeds, namely fast, regular and slow. In every case, the up and down stages of the push-up cycle were indicated audibly by an electronic metronome. For the fast push-up repetitions, the metronome was set to 84 beats per minute (bpm), i.e., 42 cycles per minute (equivalent to 7 push-ups/10s). Meanwhile, for the regular and slow push-up repetitions, the metronome beat was set to 60 bpm (5 push-ups/10 s) and 48 bpm (4 push-ups/10 s), respectively. The investigation commenced with the fast push-up tests. The subjects were instructed to perform push-ups for 15 seconds in accordance with the instructed cadence. After 15 seconds, the subjects were told to wait for around 5 seconds to allow for data recording, and were then requested to repeat the same procedure (i.e., push-ups for 15 seconds followed by a 5 second pause) until they were completely fatigued, i.e., they had completely exhausted their energy and stamina, and were

physically unable to perform any more repetitions. Following a rest period of two weeks, the experimental procedure was repeated at the regular push-up speed. Finally, following a further two-week rest period, the experimental procedure was repeated once again at the slow push-up speed.

2.2 Statistical analysis

The number of push-up repetitions, the endurance time, the myodynamic decline data, and the sEMG data were analyzed using SPSS statistical software (SPSS Inc., Chicago, Illinois, USA). In addition, the myodynamic decline data and sEMG data were analyzed via repeated-measure one-way analysis of variance (rmANOVA) tests using a significance level of $P < 0.05$. In performing the tests, the push-up speed was treated as the independent variable and the myodynamic decline rate and the TMA were treated as dependent variables. A post-hoc analysis of the effect of the push-up speed on the dependent variables was performed using the Bonferroni method.

3. Results

3.1 Total number of push-up repetitions and endurance time

In performing the push-up tests, the subjects were asked to try and keep up with the designated push-up speed as best as they could, even as they became tired. The average cycle times of the fast, regular and slow push-ups were found to be 1.67 ± 0.14 s, 2.14 ± 0.09 s and 2.63 ± 0.07 s, respectively. Even though the average cycle time was longer than the instructed cadence as a result of the subjects becoming tired, a significant difference existed in the average cycle times of the tests performed at the three different push-up speeds. Table 1 presents the statistical results for the maximum number of push-ups before fatigue and the endurance time at each of the three push-up speeds. As shown, a significant difference ($P = 0.012$) existed in the maximum number of push-ups performed at the three different speeds. In addition, it is observed that the maximum number of push-ups was obtained at the highest push-up speed. Finally, it is seen that the endurance time at the slow push-up speed (101.2 s) was significantly longer ($p = 0.038$) than that at the fast or regular push-up speed.

Table 1. Maximum number of push-up repetitions and endurance time for push-ups performed at various speeds until fatigue.

Push-up speed	Fast [¶] mean (SD)	Regular [†] mean (SD)	Slow [‡] mean (SD)	P^{\S}	Post hoc
Number of times	51.3 (13.9)	38.2 (8.5)	38.6 (7.5)	0.012*	F>R, S
duration time (sec)	84.2 (17.3)	81.3 (16.7)	101.2 (18.9)	0.038*	S>F, R

¶ F: fast push-up speed
 † R: regular push-up speed
 ‡ S: slow push-up speed
 § P value is significance of one-way ANOVA.
 * Significant differences ($P < 0.05$) among three push-up speeds.

3.2 Effect of push-up speed on myodynamic decline rate

Table 2 shows the myodynamic decline rate for each of the ten isometric conditions following completion of the fast,

regular and slow push-up tests, respectively. The results show that a myodynamic decline of more than 45% occurred in the SE, SF, SAB, SAD, EE and EF isometric tests. However, for a given isometric test condition, there was no significant difference in the myodynamic decline rate among the three different push-up speeds.

Table 2. Rate of myodynamic decline following push-ups performed at various speeds until fatigue.

Push-up speed	Fast	Regular	Slow	P^{\S}
	Mean decline rate	Mean decline rate	Mean decline rate	
Shoulder				
SE	50.62%	48.61%	51.11%	0.933
SF	49.27%	40.49%	47.30%	0.399
SAB	47.85%	48.65%	51.95%	0.721
SAD	50.86%	48.78%	49.92%	0.943
SRE	39.12%	42.28%	41.56%	0.812
SRI	37.74%	42.29%	40.36%	0.687
Elbow				
EE	44.27%	43.07%	44.69%	0.938
EF	46.48%	40.94%	44.52%	0.549
Forearm				
FS	37.75%	35.15%	38.21%	0.730
FP	35.01%	34.42%	37.17%	0.845
P^{\S}	0.007**	0.015*	0.236	
Post hoc				
	SE > SRE, SRI, FS, FP	SE > FS, FP	SE > FP	
	SF > SRI, FS, FP	SAB > FS, FP	SAB > FS, FP	
	SAB > FP	SAD > FS, FP		
	SAD > SRE, SRI, FS, FP			
	EF > FP			

§ P value shows significance by one-way ANOVA.
 * Significant differences ($P < 0.05$) among ten isometric tests.
 ** Significant differences ($P < 0.01$) among ten isometric tests.

3.3 Variation in myodynamic decline rate among different isometric test conditions

Table 2 shows that for each push-up speed, a significant difference existed in the myodynamic decline rates associated with the different isometric conditions (i.e., $P = 0.007$, 0.015 and 0.236 for the fast, regular and slow push-up speeds, respectively).

3.4 Muscle activity

Table 3 presents the TMA results for each of the 10 muscle groups over the full duration of the fast, regular and slow push-up tests, respectively. It can be seen that for all muscle groups, the TMA in the slow push-up tests was significantly higher than that in the regular push-up tests or fast push-up tests. The higher TMA was particularly apparent in the biceps brachii, triceps brachii, ($P < 0.05$), anterior deltoid, posterior deltoid, and posterior deltoid muscle groups ($P = 0.053\sim 0.058$).

4. Discussion

The experimental results presented in this study show that push-ups have a significant effect on the upper-extremity strengthening process. Table 2 shows that a myodynamic decline occurred in each of the considered isometric test conditions following the push-up exercises. However, for a given isometric condition, the push-up speed had no significant

Table 3. Total muscle activation (TMA) over whole push-up cycle for push-ups performed at various speeds.

Push-up Speed	Fast [¶] Mean (SD)	Regular [†] Mean (SD)	Slow [‡] Mean (SD)	P [§]	Post hoc
Supinator	1261.56 (752.15)	1149.39 (619.87)	1641.85 (1075.29)	0.425	
Pronator teres	941.04 (367.58)	1119.98 (749.27)	1530.81 (858.11)	0.200	
Triceps brachii	2138.91 (775.92)	2038.74 (526.01)	3145.29 (1044.76)	0.012**	S>F, R
Middle deltoid	1243.85 (535.12)	1568.75 (818.10)	2205.96 (1191.52)	0.104	
Biceps brachii	714.37 (288.00)	806.07 (692.50)	1732.77 (775.09)	0.006**	S>F, R
Anterior deltoid	1612.20 (730.92)	1636.69 (449.21)	2295.36 (707.65)	0.053	
Pectoralis major	2114.23 (814.05)	2249.87 (968.03)	3121.81 (988.68)	0.054	
Posterior deltoid	1159.48 (517.40)	1378.25 (584.92)	2217.42 (1399.48)	0.058	
Infraspinatus	1216.83 (691.58)	1381.67 (926.22)	1973.02 (1018.66)	0.207	
Teres minor	1381.88 (994.21)	1619.22 (722.59)	2431.47 (1065.04)	0.055	

unit: %MVIC sec

¶ F: fast push-up speed

† R: regular push-up speed

‡ S: slow push-up speed

§ P value shows significance by one-way ANOVA.

** Significant differences ($P < 0.01$) among three push-up speed.

effect on the myodynamic decline rate. This result is to be expected since the myodynamic decline rate was measured once the subjects were completely fatigued, irrespective of the speed at which the repetitions were performed.

However, for a given push-up speed, the myodynamic decline rates measured under the different isometric conditions were significantly different. As shown in the lower row of Table 2, the difference in the myodynamic decline rate among the different isometric conditions was more significant following the push-up tests performed at a fast speed ($P = 0.007$) than following the tests performed at the regular speed ($P = 0.015$) or the slow speed ($P = 0.236$). In other words, the difference in the effort exerted by the different upper extremity muscle groups increased as the push-up speed increased, but reduced as the push-up speed reduced. This finding can be explained by considering the effect of the push-up speed on the different usage of the muscle groups.

As shown in Fig. 2, the peak EMG activity of the triceps brachii muscle group occurred at the lowest position of the push-up cycle at all three push-up speeds. However, the peaks in the EMG curve obtained in the slow push-up test were lower and broader than those in the curves obtained in the fast push-up test. In the fast push-up tests, the muscle groups did not need to support the body weight for a prolonged period of time during the “descending” stage and “ascending” stages. Instead, they were used predominantly to control the deceleration of the body at the end of the “descending” stage and to control the acceleration of the body at the beginning of the “ascending stage”. By contrast, in the slow push-up tests, the muscle groups were required to drive the body at a more consistent speed throughout the entire push-up cycle. In general, the change in acceleration when switching from the “descending” stage of the repetition to the “ascending” stage is accomplished using a subset of the upper extremity muscle groups, i.e., the posterior deltoid, anterior deltoid, middle deltoid, pectoralis major, triceps brachii and biceps brachii [9,10]. However, supporting the body weight over the entire push-up cycle involves all of the muscle groups. As a result, the difference in the myodynamic decline rate observed under

different isometric conditions was more noticeable following the high-speed tests than after the regular or slow-speed tests.

Table 2 shows that the largest myodynamic decline rates occurred in the SE, SF, SAB, SAD, EE, and EF isometric test conditions, which involved the posterior deltoid, anterior deltoid, middle deltoid, pectoralis major, triceps brachii and biceps brachii muscle groups, respectively [12]. These muscle groups correspond exactly with those groups responsible for controlling the change in acceleration during the push-up cycle. Therefore, it can be inferred that irrespective of the speed at which the push-ups are performed, the process of controlling the change in acceleration of the body weight is responsible for most of the energy consumed in each push-up cycle.

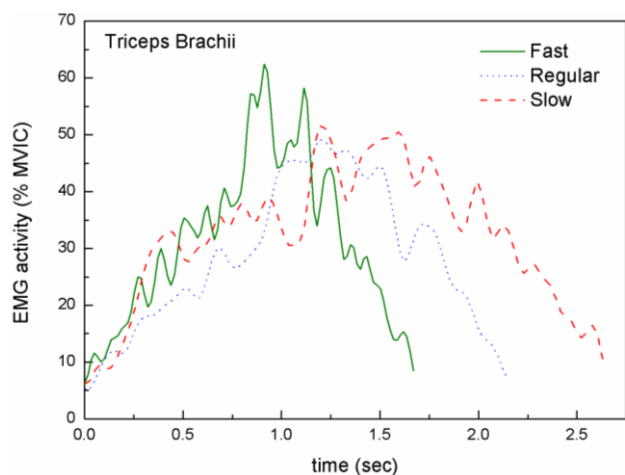


Figure 2. Mean normalized EMG activity of triceps brachii during a single push-up cycle.

Table 1 shows that the maximum number of repetitions at a fast push-up speed was significant higher than that at a regular push-up speed or slow push-up speed. However, Table 3 shows that a faster push-up speed did not result in a greater muscle activation. Among the three push-up speeds, the slow push-up speed resulted in a significantly larger TMA than the regular or fast push-up speed. Since, a similar number of repetitions were performed at the slow and regular push-up speeds, respectively, the larger TMA at a slow push-up speed

was most likely the result of a longer endurance time. That is, the subjects spent a greater amount of time supporting their body weight prior to fatigue when performing the push-ups at a slow speed than when performing the push-ups at a regular speed.

5. Conclusions

This study examined the effect of the push-up speed (fast, regular and slow) on the myodynamic decline rate and activation of the upper extremity muscle groups. At a fast push-up speed, the maximum number of push-up repetitions prior to fatigue was found to be 1.34 and 1.33 times higher than that at a regular push-up speed or slow push-up speed, respectively. However, the endurance time (i.e. the time to fatigue) at a slow push-up speed was around 1.20 and 1.24 times longer than that at a fast push-up speed or regular push-up speed, respectively. In addition, at a slow push-up speed, the TMAs of the triceps brachii, biceps brachii, anterior deltoid, pectoralis major, and posterior deltoid muscle groups were 1.47, 2.43, 1.42, 1.48, and 1.91 times higher than those at a fast push-up speed, respectively. Finally, the myodynamic decline rate of the upper extremity muscles was found to be independent of the push-up speed. Overall, the results suggest that a slow push-up speed delays the occurrence of fatigue and increases the muscle activation. By contrast, a fast push-up speed increases the maximum number of push-up repetitions, but reduces the muscle activation. Accordingly, the present findings suggest two different push-up strategies. That is, when a certain number of push-up repetitions are to be performed (e.g., as part of military training), the repetitions should be performed at a faster speed since this requires a lower muscle activation and less effort. Conversely, when the aim is to develop upper-body strength (e.g., in athletic training), the push-ups should be performed more slowly since this increases the muscle activation.

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