Kinetic Analysis of Several Variations of Push-Ups

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Abstract

Ebben, WP, Wurm, B, VanderZanden, TL, Spadavecchia, ML, Durocher, JJ, Bickham, CT, and Petushek, EJ. Kinetic analysis of several variations of push-ups. *J Strength Cond Res* 25(10): 2891–2894, 2011—Push-ups are a common and practical exercise that is used to enhance fitness, including upper body strength or endurance. The kinetic characteristics of push-ups and its variations are yet to be quantified. Kinetic quantification is necessary to accurately evaluate the training load, and thus the nature of the training stimulus, for these exercise variations. This study assessed the peak vertical ground reaction forces (GRFs) of push-up variations including the regular push-up and those performed with flexed knee, feet elevated on a 30.48-cm box, and a 60.96-cm box, and hands elevated on a 30.48-cm box and a 60.96-cm box. Twenty-three recreationally fit individuals (14 men, 9 women) performed each of the 6 push-up variations in a randomized order. Peak GRF and peak GRF expressed as a coefficient of subject body mass were obtained with a force platform. Push-ups with the feet elevated produced a higher GRF than all other push-up variations ($p \leq 0.05$). Push-ups with hands elevated and push-ups from the flexed knee position produced a lower GRF than all other push-up variations ($p \leq 0.05$). No gender differences in response to these push-up variations were found ($p > 0.05$). Additionally, subject height was not related to the GRF for any of the push-up conditions ($p > 0.05$) other than the condition where hands were elevated on a 60.96-cm box ($p \leq 0.05$; $r = 0.63$). These data can be used to progress the intensity of push-ups in a program and to quantify the training load as a percentage of body mass.

Key Words strength, body weight, upper body, closed kinetic chain, exercise progression

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Introduction

Push-ups are a commonly performed, easy to execute, multijoint upper body exercise that do not require expensive equipment. Thus, they can be readily included in a fitness program. In fact, push-ups have been recommended by a popular consumer publication as one of the best practical upper body exercises that can be used to enhance fitness (12). Push-ups are one of a limited number of closed kinetic upper body exercises (2), and there are many potential variations that can be used or prescribed (15).

Push-ups have also been evaluated as an upper body strength test (14) and are often included on standardized fitness tests including those used for school children (13) and military recruits (9). Training with traditional and plyometric push-ups produces increased upper body strength and power (17). Push-ups are also commonly used to evaluate muscular endurance and can be modified to yield similar results between men and women (11). Thus, push-ups are used, and their quantification can be of value for programs designed for youth, general fitness, and military recruits. Unfortunately, the quantification of this exercise in a training program is difficult compared to traditional resistance training exercises.

Resistance training exercises are often performed with equipment such as a barbell and weight plates with clearly labeled masses. These loads are often calculated, and exercises are performed with a percentage of the exerciser's maximum ability. Determination of the intensity of a resistance training stimulus allows for the progression of exercise intensity and the calculation of training volume. The quantification of push-ups intensity is more difficult.

Research quantifying push-ups and its variations is limited. Studies have examined muscle activation of push-ups typically examining variations in hand placement (4,6,8,16). Other investigations have compared the traditional push-up to a push-up using a manufactured product, or a specific variation in exercise technique, using electromyography to assess the differences (3,16). Only one study used ground reaction forces (GRFs) to assess variations in push-ups characterized by differences in hand position and a bent knee condition. This study described the push-up as a percentage of body weight and demonstrated differences in GRF between variations of hand placement and between bent knee and normal push-up conditions (8). However, many variations of push-ups have not been studied such as conditions that include elevated feet or hands. These different types of push-ups can be readily prescribed in fitness settings potentially offering variation to the program and a range of low to higher intensity options.

Kinetic quantification of body mass exercises allows for the estimated quantification of the training load and intensity, which has been proposed to be important to calculate load volume, metabolic demand, and work in a periodized program (1). With free-weight exercises, this process is relatively easy because load volume is based on the mass of the barbell and weight plates. For exercises that include some portion of body mass, determining this load is more complex.

The purpose of this study was to assess the peak GRF associated with regular push-ups, and those performed with flexed knee, feet elevated on a 30.48-cm box, feet elevated on a 60.96-cm box, hands elevated on a 30.48-cm box, and hands elevated on a 60.96-cm box for the purpose of quantifying the loads of these exercises for exercise intensity progression and to allow for the calculation of exercise load and volume in a program. This study also sought to assess if there were gender-based differences in response to these push-up variations and the relationship between subject height and peak GRF.

Methods

Experimental Approach to the Problem

This study tested the hypothesis that there were differences in peak GRF and peak GRF expressed as a coefficient of body mass for a number of push-up variations and the role of gender in these variables. This study also sought to assess the relationship between subject height and peak GRF and peak GRF expressed as a coefficient of body mass. A randomized repeated measures research design was used with subjects performing 6 push-up variations. Independent variables included the push-up variations assessed, gender, and subject height. Dependent variables included the peak GRF and peak GRF expressed as a coefficient of body mass for the push-up variations assessed in this study.

Subjects

Twenty-three recreationally fit young adults including 14 men (mean ± *SD*; age = 22.5 ± 3.6 years, height = 179.81 ± 10.89 cm, body mass = 83.70 ± 11.28 kg) and 9 women (mean ± *SD*; age = 21.1 ± 1.6 years, height = 173.43 ± 9.37 cm, body mass = 69.34 ± 7.90 kg) volunteered to serve as subjects for the study. Subjects signed an informed consent form, and Institutional Review Board approval was obtained before the study.

Procedures

Subjects were instructed in and received demonstration of each push-up variation including a regular push-up, and those performed with flexed knee, feet elevated on a 30.48-cm box, feet elevated on a 60.96-cm box, hands elevated on a 30.48-cm box, and hands elevated on a 60.96-cm box. For all warm-up, practice, and test push-ups, subjects' hand placement was defined as the width equal to the distance of contralateral acromion processes measured from the inside border of each hand with hands placed under the shoulders in the beginning position, which was characterized by full elbow extension.

Subjects warmed up by performing 3 repetitions of each push-up variation in a randomized order. After 2 minutes of rest, subjects performed 2 repetitions of each push-up variation in randomized order. Subjects rested for 1 minute in between each push-up variation. A metronome was used to control the cadence of the push-up repetitions with each repetition performed for a count of 2 seconds in each of the eccentric and concentric phase. A relatively fast pace was desired because previous research demonstrated higher levels of power and work for fast compared to slower cadences (10) and the 2-second cadence has been demonstrated to be effective at increasing upper body strength (17).

The push-up variations were assessed with a 60 × 120-cm force platform (BP6001200, Advanced Mechanical Technologies, Inc., Watertown, MA, USA), which was calibrated with known loads to the voltage recorded before the testing session. Data were collected at 1,000 Hz, real time displayed, and saved with the use of computer software (BioAnalysis 3.1, Advanced Mechanical Technologies, Inc.) for later analysis. All values were determined as the average of 2 trials for each push-up variation. Peak GRF and peak GRF expressed as

Table 1. Push-up peak GRF expressed as a coefficient of total body mass ground reaction force (n = 23).*†

Push-up variation	Body weight coefficient‡
FE 60.96	0.74 ± 0.02
FE 30.48	0.70 ± 0.02
R	0.64 ± 0.04
HE 30.48	0.55 ± 0.05
FK	0.49 ± 0.05
HE 60.96	0.41 ± 0.06

*FE 30.48 = feet elevated on a 30.48-cm box; FE 60.96 = feet elevated on a 60.96-cm box; R = regular; HE 30.48 = hands elevated on a 30.48-cm box; HE 60.96 = hands elevated on a 60.96-cm box; FK = flexed knee; GRF = ground reaction force.

†Values are given as mean ± *SD.*

‡Significantly different from all other push-up conditions ($p \leq 0.01$).

TABLE 2. Push-up peak GRF for each push-up variation ($n = 23$).*†

Push-up variation	Peak GRF (N)
FE 60.96	723.89 ± 138.24‡
FE 30.48	714.05 ± 142.61§
R	700.13 ± 138.25‖
HE 30.48	681.46 ± 125.31‖
HE 60.96	596.75 ± 113.43‖
FK	569.92 ± 138.24‖

*FE 30.48 = feet elevated on a 30.48-cm box; FE 60.96 = feet elevated on 60.96-cm box; R = regular; HE 30.48 = hands elevated on a 30.48-cm box; HE 60.96 = hands elevated on a 60.96-cm box; FK = flexed knee; N = newtons; GRF = ground reaction force.

†Values are given as mean ± *SD*.

‡Significantly different ($p \leq 0.05$) from all other push-up conditions except FE 30.48.

§Significantly different ($p \leq 0.05$) from all other push-up conditions except FE 60.96.

‖Significantly different ($p \leq 0.05$) from all other push-up conditions.

a coefficient of body mass were evaluated from the vertical force–time records using custom-designed software.

Statistical Analyses

Data were analyzed using SPSS 16.0 using 2-way mixed analysis of variance (ANOVA) with repeated measures for push-up variations and to assess the interaction between push-up variations and gender. Bonferroni-adjusted pairwise comparisons identified the specific differences between these variations. A Pearson's correlation coefficient estimation was conducted to assess the relationship between peak GRF expressed as a coefficient of body mass and subject height. The trial-to-trial reliability was assessed for the peak GRF and peak GRF expressed as a coefficient of body mass for each push-up variation using both single (intraclass correlation [ICC]single) and average (ICCave) measures ICCs. The ICC classifications of Fleiss (7) (<0.4 was poor, between 0.4 and 0.75 was fair to good, and >0.75 was excellent) were used to describe the range of ICC values. In addition, a repeated-measures ANOVA was used to confirm that there was no significant difference in peak GRF and peak GRF expressed as a coefficient of body mass for between trials. The a priori alpha level was set at $p \leq 0.05$. Effect sizes and power are reported as η^2_p and d, respectively.

RESULTS

Results revealed a significant main effect for push-up condition for peak GRF expressed as a body weight coefficient ($p \leq 0.001$, $\eta^2_p = 0.94$, $d = 1.00$), with no interaction between push-up condition and gender for this variable ($p > 0.05$). There was also a significant main effect for peak GRF ($p \leq 0.001$, $\eta^2_p = 0.76$, $d = 1.00$) with no interaction between condition and gender for this variable ($p > 0.05$). Results of pairwise comparisons of peak GRF expressed as a body weight coefficient, and peak GRF, are presented in Tables 1 and 2, respectively.

Subject height was not correlated to peak GRF expressed as a body weight coefficient ($p > 0.05$) for all push-up variations except for the hands elevated 60.96-cm variation ($p = 0.001$; $r = 0.63$). Trial-to-trial reliability of the peak GRF expressed as a body weight coefficient was moderately to highly reliable (7) as demonstrated by single and average measures ICC values in a range from 0.64 to 0.84 with no significant differences between trials ($p > 0.05$). Trial-to-trial reliability of the mean peak GRF was highly reliable (7) as demonstrated by single and average measures ICC values in the range from 0.97 to 0.99 with no significant differences between trials ($p > 0.05$).

DISCUSSION

This is the first study to assess push-up variations that include different levels of feet and hand elevation, and bent knee and normal positions. A variety of differences were found between most of these conditions. Results of this study can be used to guide the progression of overload, by incorporating the push-up variations with higher GRF throughout a program. Progression of overload is believed to be important for exercise program design (5). This study also allows the quantification of training load, as an estimated coefficient of body mass, because quantifying training load is an important component of program design (1).

The results of this study demonstrated a GRF of approximately 64 and 49% of body weight in the regular and bent knee push-up conditions, respectively. These findings were slightly different from the values previously found, which were 66 and 53%, for the regular and flexed knee push-up variations, respectively (8). Previous research showed that changes in hand placement produce a GRF in a range from 52.9 to 72.9% of body mass (8). In this study, push-up conditions that included hand elevation of 60.96 cm produced a GRF as low as 41% of body mass and as high as 74% of body mass when the feet were elevated 60.96 cm. Thus, it is possible to progress push-ups from low intensity with hands elevated, to high intensity via feet elevation. These results show that exercise intensity can increase up to 33% from progressing from the lowest intensity to highest intensity push-up variations. No previous study has assessed variations of hand and feet elevation during the push-up. Previous research has commonly used electromyography to assess hand placement including wide and narrow grip (4,6,8), anterior and posterior hand position (6,8), or one-arm push-ups (6). These studies demonstrate varied results with respect to muscle activation. The flexed knee push-up option has been used as a gender modification for women in some studies (11). In this study, this variation represented 49% of body mass, compared to the regular push-up condition which produced 64% of body mass. Results indicate that the kinetic characteristics of these push-up variations do not differ between men and women. Similarly, subject height was not correlated with GRF, except for the condition in which the hands were elevated to 60.96 cm. Thus, other than this latter exception, these data apply similarly for both men and women and regardless of subject height.

Practical Applications

Practitioners in fitness settings should use the body weight coefficient data presented in this study to understand the progression of push-up intensity from lower to higher intensity push-up variations. These data can also be used to quantify the approximate load as a percentage of body mass for the purpose of quantifying load and volume in a resistance training program to enhance upper body fitness.

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