EFFECTS OF DIFFERENT RELATIVE LOADS ON POWER PERFORMANCE DURING THE BALLISTIC PUSH-UP

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ABSTRACT

Wang, R, Hoffman, JR, Sadres, E, Bartolomei, S, Muddle, TWD, Fukuda, DH, and Stout, JR. Effects of different relative loads on power performance during the ballistic push-up. J Strength Cond Res XX(X): 000–000, 2017—The purpose of this investigation was to examine the effect of load on force and power performance during a ballistic push-up. Sixty (24.5 ± 4.3 years, 1.75 ± 0.07 m, and 80.8 ± 13.5 kg) recreationally active men who participated in this investigation completed all testing and were included in the data analysis. All participants were required to perform a 1 repetition maximum bench press, and ballistic push-ups without external load (T1), with 10% (T2) and 20% (T3) of their body mass. Ballistic push-ups during T2 and T3 were performed using a weight loaded vest. Peak and mean force, power, as well as net impulse and flight time were determined for each ballistic push-up. Peak and mean force were both significantly greater (p < 0.01) during T3 (1,062 ± 202 and 901 ± 154 N, respectively), than both T2 (1,017 ± 202 and 842 ± 151 N, respectively) and T1 (960 ± 188 and 792 ± 140 N, respectively). Peak and mean power were significantly greater (p < 0.01) during T1 (950 ± 257 and 521 ± 148 W, respectively), than both T2 (872 ± 246 and 485 ± 143 W, respectively) and T3 (814 ± 275 and 485 ± 162 W, respectively). Peak and mean power were greatest during T1, regardless of participants’ strength levels. Significant (p < 0.01) greater net impulse and smaller peak velocity and flight time were also noted from T1 to T3. Results of this investigation indicated that maximal power outputs were achieved without the use of an external load when performing the ballistic push-up, regardless of the participants’ level of strength.

KEY WORDS optimal intensity, strength, force-time curve, upper-body strength

INTRODUCTION

Muscular power is considered to be one of the main determinants for many explosive, short-duration sporting events (24). The determination of muscular power originates from the force-velocity relationship proposed by Hill (12), who found that an isolated muscle contracts at a velocity inversely proportional to the intensity of the action. During single joint movements, peak power was reported to be achieved at approximately 30% of maximal isometric strength (16), or at 55% of 1 repetition maximum (1RM) (22). For multijoint muscle actions, the optimal intensity varies with the exercise. Baker et al. (4) reported that peak power occurred at an intensity ranging between 55 and 59% of the participants 1RM in the jump squat exercise. Others have reported that peak power in Olympic weightlifting movements occur between 70 and 80% 1RM (17). Cronin et al. (8) reported that peak power was noted at 50–70% 1RM during bench press and bench throw exercises. The resistance of body mass needs to be overcome during the aforementioned multijoint exercises. However, most studies have neglected this issue which may explain the variation in the optimal intensity for certain exercises. McBride et al. (19) examined jump squat performance with various loads and reported that peak power was significantly higher at unloaded conditions (body mass only) in comparison with 20 and 40% of 1RM. In consideration of the importance associated with maximizing power performance during resistance training, identifying the optimal intensity for certain exercises, especially those involved with body mass resistance, becomes important.

Resistance training programs incorporating explosive movements such as the power clean and squat jump have been demonstrated to be superior for developing peak power than traditional powerlifting movements (14,18,27). However, there seems to be limits in the explosive movements that can be used as an upper-body exercise to enhance power performance in that specific region of the body. Although the bench press throw has been investigated (4,8,23), the need for specific equipment and spotters may limit its use during daily training. Push-ups have been proposed to be an alternative exercise to enhance upper-body power gains if muscle activation is sufficient (5). Previously, it
has been demonstrated that the inclusion of the ballistic push-up could benefit upper-body strength and power (18). However, some investigators have indicated that push-ups performed unloaded (individuals body mass only) may not maximize upper-body strength and power gains (10,11). As such, it has been proposed that increasing the intensity of the exercise by wearing a weighted vest may improve performance outcomes (6,10). However, to the best of our knowledge, no study has investigated the effect of different loads, expressed as a percentage of body mass, on maximizing power output during the ballistic push-up.

Therefore, the purpose of this investigation was to determine whether external load is needed to maximize power output in the ballistic push-up in recreationally active men. We sought to further examine the influence of strength, as determined by relative 1RM bench press, on this load-power relationship for the ballistic push-up. Our directional hypothesis is that body mass alone is sufficient to provide enough resistance to produce greater power output than loaded with 10 and 20% body mass in the ballistic push-up, regardless of the strength level of the participant.

**METHODS**

Experimental Approach to the Problem
A cross-sectional design was used to examine the optimal load for the ballistic push-up. All study participants reported to the laboratory on 3 separate occasions. During the first visit, participants were familiarized with the ballistic push-up. During the following 2 visits, participants completed ballistic push-up testing and 1RM bench press testing in a random order.

Subjects
Eighty-four recreationally active men who were familiar with weightlifting volunteered to participate in this investigation. Sixty participants (24.5 ± 4.3 years [range = 18–35 years], 1.75 ± 0.07 m, and 80.8 ± 13.5 kg) completed all testings. The study was approved by the University's Institutional Review Board. Testing procedures were fully explained to each participant before obtaining their signed informed consent. In an attempt to eliminate the potential of fatigue, participants were asked to refrain from any strenuous physical activity for the previous 48 hours.

Ballistic Push-up Testing
Before beginning the test, each participant completed a general warm-up that included dynamic movements and 5 minutes of cycling exercise. They were instructed to adopt a prone position on the force plate (AccuPower; AMTI, Watertown, MA, USA) with their hands placed approximately shoulder width apart at a self-selected, comfortable distance. They were asked to move into the starting position by lowering themselves until their chest made contact with the force plate, while keeping their body straight. Once stable in the starting position, participants were then instructed to push as explosively as possible to full arm extension and achieve as much height as possible with hands leaving the force plate. They performed 6 ballistic push-up trials, 2 at each condition: without external load (T1), with a weighted vest containing resistance equaling 10% (T2) and 20% (T3) of their body mass. The order of the trials were not randomized, and occurred from T1 to T3. A rest interval of 3–5 minutes was provided between trials to ensure recovery. All trials were completed under the supervision of a certified strength and conditioning specialist.

Maximal Strength Testing
A 1RM bench press test was performed using methods previously described by Hoffman (13). Before beginning the test, each participant completed a general warm-up that included dynamic movements and 5 minutes of cycling exercise. Each participant then performed 2 warm-up sets using a resistance that was approximately 40–60% and 60–80% of their estimated 1RM, respectively. The third set was the first attempt at the participant's 1RM. If the set was successfully completed, then weight was added and another set was attempted. If the set was not successfully completed, then the weight was reduced and another set was attempted. A 3–5 minutes rest period was provided between each set. This process of adding and removing weight was continued until 1RM was reached. Attempts that did not meet the range of motion criterion for each exercise, as determined by the researcher, were discarded. The participants were required to lower the bar to their chest before initiating concentric movement. Their grip widths were measured and recorded for later use. All testings were completed under the supervision of a certified strength and conditioning specialist. To examine the effect of strength on power performance, participants were separated into 3 groups (G1, G2, and G3) based on relative 1RM bench press strength criteria previously published by the American College of Sports Medicine (20).

Data Processing
The vertical force-time data for each ballistic push-up trial was recorded with a sample rate of 1,000 Hz and then processed using a customized MATLAB (The MathWorks, Inc., Natick, MA, USA) program. The initial mass was determined from the stable phase in the starting position. Peak force and mean force were defined as the highest and average force achieved during the concentric phase of the push-up movement, respectively. The test-retest reliability, as determined by interclass correlation coefficient (ICC) and standard error of measurement (SEM), for peak and mean force was ICC = 0.97 (SEM = 45 N) and 0.99 (SEM = 21 N), respectively. The test-retest reliability for net impulse was ICC = 0.96 (SEM = 5.9 N·s). Peak power and mean power were defined as the highest and average power output resulted from the impulse-momentum relationship, as described previously (7). The test-retest reliability for peak and mean power was ICC = 0.88 (SEM = 123 W) and 0.90
test of sphericity. As suggested previously (21), the effect size correction was used in the case of the violation of Mauchly's determination significant differences. Greenhouse-Geisser pairwise comparisons with Bonferroni F ratios, respectively.

Statistical Analyses
The best trial at each loading condition, as determined by mean power output, was included into the statistical analysis. The Shapiro-Wilk test was conducted to test normality of each variable. Comparisons between trials (T1, T2, and T3) were performed with a one-way analysis of variance (ANOVA) with repeated measures. To compare the effect of strength on both peak and mean power performances, we performed a 2-way mixed (group × trial) ANOVA with repeated measures. In the event of a significant F ratio, pairwise comparisons with Bonferroni correction were used to determine significant differences. Greenhouse-Geisser correction was used in the case of the violation of Mauchly's test of sphericity. As suggested previously (21), the effect size was determined by partial eta squared (η²) and interpreted as small (0.01), medium (0.06), and large (0.14). The concurrent changes in velocity as the external load increases were also examined and the linear regression line was derived for each group. All data were analyzed using IBM SPSS Statistics for Windows version 22.0 (IBM Corp., Armonk, NY, USA). Data are presented as mean ± SD (Table 1).

RESULTS

The Effect of Different Loads on Performance Measurements
Differences in performance measurements between T1, T2, and T3 can be observed in Figure 1. Significant differences were observed in both peak force ($F_{(2,118)} = 100.794, p < 0.001$, and $\eta^2 = 0.631$) and mean force ($F_{(2,118)} = 370.505, p < 0.001$, and $\eta^2 = 0.863$) between trials. Pairwise comparisons revealed that both peak and mean force were significantly lower during T1 than T2 ($p < 0.001$) and T3 ($p < 0.001$).

Net impulse was significantly different between trials ($F_{(2,118)} = 19.583, p < 0.001$, and $\eta^2 = 0.249$). Pairwise comparisons demonstrated that net impulse increased significantly from T1 to T2 ($p = 0.001$) and T3 ($p < 0.001$). Significant differences were also noted for peak ($F_{(2,118)} = 31.500, p < 0.001$, and $\eta^2 = 0.348$) and mean power ($F_{(2,118)} = 21.112, p < 0.001$, and $\eta^2 = 0.264$). Pairwise comparisons indicated that peak power decreased significantly from T1 to T2 ($p < 0.001$) and T3 ($p < 0.001$). Differences between T2 and T3 were also significant ($p < 0.001$). Significant decreases in the mean power were observed between T1 and both T2 ($p = 0.001$) and T3 ($p < 0.001$). Differences were also noted between T2 and T3 ($p = 0.004$) in mean power.

The peak velocity differed significantly between trials ($F_{(2,118)} = 161.700, p < 0.001$, and $\eta^2 = 0.733$). Pairwise comparisons demonstrated that the peak velocity increased significantly from T1 to both T2 ($p < 0.001$) and T3 ($p < 0.001$). Significant differences were also observed between T2 and T3 ($p < 0.001$). A significant difference in the flight time was noted between trials ($F_{(2,118)} = 68.801, p < 0.001$, and $\eta^2 = 0.538$). Pairwise comparisons indicated that the flight time decreased significantly from T1 to T2 ($p < 0.001$) and T3 ($p < 0.001$). Differences in the flight time were also observed between T2 and T3 ($p < 0.001$).

The Effect of Strength on Peak and Mean Power Outputs
No interactions were found between groups and trials for either peak ($F_{(4,92.2)} = 0.786, p = 0.513$, and $\eta^2 = 0.027$) or mean power ($F_{(4,97.9)} = 0.906, p < 0.452$, and $\eta^2 = 0.031$).

### Table 1. Comparison of anthropometric measures of participants between groups.

<table>
<thead>
<tr>
<th>Group</th>
<th>G1</th>
<th>G2</th>
<th>G3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>24.72 ± 4.16</td>
<td>24.22 ± 4.17</td>
<td>24.54 ± 4.75</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.77 ± 0.07</td>
<td>1.76 ± 0.07</td>
<td>1.74 ± 0.07</td>
</tr>
<tr>
<td>Body Mass (kg)</td>
<td>80.19 ± 15.29</td>
<td>80.80 ± 13.47</td>
<td>81.15 ± 12.71</td>
</tr>
<tr>
<td>1RM (kg)</td>
<td>92.17 ± 18.42</td>
<td>112.37 ± 17.11†</td>
<td>131.35 ± 22.17‡</td>
</tr>
<tr>
<td>1RM/Body Mass</td>
<td>1.15 ± 0.11</td>
<td>1.39 ± 0.051†</td>
<td>1.62 ± 0.10‡</td>
</tr>
<tr>
<td>T1 Peak Power (W)</td>
<td>805 ± 187</td>
<td>950 ± 218</td>
<td>1,057 ± 283</td>
</tr>
<tr>
<td>T2 Peak Power (W)</td>
<td>734 ± 163</td>
<td>850 ± 198</td>
<td>993 ± 276</td>
</tr>
<tr>
<td>T3 Peak Power (W)</td>
<td>638 ± 171</td>
<td>817 ± 210</td>
<td>944 ± 313</td>
</tr>
<tr>
<td>T1 Mean Power (W)</td>
<td>447 ± 107</td>
<td>517 ± 116</td>
<td>581 ± 172</td>
</tr>
<tr>
<td>T2 Mean Power (W)</td>
<td>406 ± 82</td>
<td>474 ± 124</td>
<td>554 ± 161</td>
</tr>
<tr>
<td>T3 Mean Power (W)</td>
<td>359 ± 117</td>
<td>462 ± 128</td>
<td>530 ± 181</td>
</tr>
</tbody>
</table>

*1RM, 1 repetition maximum.
†Indicates significantly different from G1.
‡Indicates significantly different from G2.
However, a main effect for trials was noted in both peak (\(F_{(4,92.2)} = 31.833, p < 0.001, \text{ and } \eta^2 = 0.358\)) and mean power (\(F_{(4,97.9)} = 21.558, p < 0.001, \text{ and } \eta^2 = 0.274\)). Pairwise comparisons with groups combined revealed that peak and mean power during T1 was significantly greater than T2 (\(p < 0.001\) and \(p = 0.001\), respectively) and T3 (\(p < 0.001\) and \(p < 0.001\), respectively). Peak and mean power during T2 was also significantly greater than T3 (\(p < 0.001\) and \(p = 0.004\), respectively). Regardless of the participants’ strength level, both peak and mean power during T1 were significantly greater than T2 or T3. A main effect for group (collapsed across trials) was also observed for both peak (\(F_{(2,57)} = 7.606, p = 0.001, \text{ and } \eta^2 = 0.211\)) and mean power (\(F_{(2,57)} = 6.705, p = 0.002, \text{ and } \eta^2 = 0.190\)). Pairwise comparisons indicated that the peak power in G1 was significantly lower than only that in G3 (\(p = 0.001\)). No differences were observed between G1 and G2 (\(p = 0.163\)) or between G2 and G3 (\(p = 0.232\)). Similarly, mean power in G1 was significantly lower than that observed in G3 (\(p = 0.002\), and no differences were noted between G1 and G2 (\(p = 0.220\)) or G2 and G3 (\(p = 0.279\)).

Figure 2 depicts peak velocity and relative mean force averaged across the participants in each group for all 3 trials. A line of best fit was derived from T1, T2, and T3 for each group, respectively. The slope values for each group indicated that changes in relative mean force was inversely related to changes in the peak velocity. The decrease in the peak velocity, as determined by the slope of the regression line, was similar between groups (\(F_{(2,56)} = 2.196 \text{ and } p = 0.121\)).
DISCUSSION

The aim of this study was to identify the optimal load for power performance in the ballistic push-up and to examine the influence of strength level on the optimal load for this exercise. We used 3 different loading conditions: without external load (T1), with external load equaling to 10% (T2) and 20% (T3) of body mass. We hypothesized that the power output from the ballistic push-up could be maximized using just body mass, regardless of the strength level of the participants. Results from this study provide evidence to support the first part of our hypothesis, as the highest power output was achieved at T1 without external load. As power is calculated as the product of force and velocity, and its optimization relies on the balance between force and velocity, we also quantified the corresponding change in each of these variables. Both peak and mean force increased between 10 and 13% on average as load increased from T1 to T3. As load increased from T1 to T3, the peak velocity decreased by 25%. Flight time also decreased by 40%, indicating that take-off velocity was reduced at higher loads. The reduced peak and mean power outputs at the heavier loading reflected an inability of elevations in force output to compensate for the decrement in velocity. In contrast from previous suggestions that bodyweight push-ups may be disadvantageous because of the lack of resistance (10,11), our results indicate that an unloaded ballistic push-up provides sufficient external resistance to generate high movement velocities resulting in greater power production than loaded with 10 and 20% of body mass. Our findings are also supported by Winter et al. (28), who suggested that power reflects the impulse-momentum relationship. Similarly, net impulse recorded in this investigation was observed to decrease with power as load was elevated.

Power performance did not seem to be influenced by the strength level. Participants in all 3 strength groups maximized their power output when performing the ballistic push-up at T1 without an external load. Although body mass was similar between groups, body mass corresponded to 66.6 ± 7.2%, 55.3 ± 3.1%, and 48.3 ± 3.9% of 1RM bench press for G1, G2, and G3, respectively. Moreover, relative strength, as determined by the ratio of 1RM bench press and body mass, was 1.15 ± 0.11, 1.39 ± 0.05, and 1.62 ± 0.10 for all 3 groups, respectively. Our results indicated that body mass alone, seems to be the optimal load to maximize power output, regardless of strength level. It has been reported that stronger individuals are capable of maintaining the peak velocity as external load increases (25). However, this contention is not supported by our findings. As shown in Figure 2, the slope of the linear regression line was −0.272, −0.225, and −0.235 for G1, G2, and G3, respectively, indicating that peak velocity decreased at a similar rate between groups as the external load increased. It also highlights the dominant contribution of velocity over force for power production in the ballistic push-up. The greater power outputs observed during T1 (lowest load) is similar to previous investigations reporting on the optimal intensity for power production in the ballistic bench press throw (3,9). Baker et al. (3) have suggested that maximal power outputs are generally observed at low-intensity levels (around 50% 1RM bench press) in competitive strength/power athletes. It is not surprising considering that the bench press throw and ballistic push-up are both ballistic movements recruiting similar muscle groups. However, the biomechanical differences between these 2 exercises should not be neglected. The bench press throw is an open-chain, single-plane exercise while the effective propulsive phase of the ballistic push-up is a closed-chain, multiplane exercise. Therefore, the muscles activated and the order of muscle activation may not be the same. It should be noted that body mass was the minimum load examined for participants in our study. This indicates that the optimal load might be lighter than body mass for individuals with relative low strength levels to maximize the power output in the ballistic push-up. From a training perspective, our findings may have important implications for individuals with similar strength levels with G1 because up to 75% of the body mass was supported by hands during push-up (26). Considering the fact that knee push-up reduced the percentage supported by hands to 60% of the body mass (26), it might be a better option for these individuals.

There are several limitations of this study. The data were derived from only 3 loads, which are less than that used in examinations of other upper-body power modalities (e.g., bench press throw) (1–4). Future studies may consider examining the ballistic push-up power output at lower loads through elevating the upper-body position, or using a knee push-up position, especially in weaker individuals. Participants in our study were all men. Future studies should explore the optimal load for power performance in women in consideration of the sex differences known in body mass distribution and upper-body strength level (15).

PRACTICAL APPLICATIONS

Traditionally, strength and conditioning professionals have had few choices for exercises targeted at upper-body power, which is crucial for athletes in various sports. The ballistic push-up requires no equipment and provides a feasible and cost-effective option that can serve as an alternative to bench press throw for upper-body power. The results of this study indicated that greater power outputs occurred while performing the ballistic push-up without any additional weight. This is consistent across individuals with varying strength levels. It should also be noted that the intensity associated with body mass may still be too high for untrained and novice athletes.

REFERENCES


