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Reliability Assessment of Ballistic Jump Squats and Bench Throws

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[1]Military Performance Division, [2]Military Nutrition Division, [3]Thermal and Mountain Medicine Division, U.S. Army Research Institute of Environmental Medicine, Natick, MA 01760.

Abstract. Alemany, J.A., C.E. Pandorf, S.J. Montain, J.W. Castellani, A.P. Tuckow, and B.C. Nindl. Reliability assessment of ballistic jump squats and bench throws. *J. Strength Cond. Res. 19(1):33–38. 2005.*—The purpose of this investigation was to determine the test-retest reliability and coefficient of variation of 2 novel physical performance tests. Ten healthy men (22.0 ± 3.0 years, 87.0 ± 8.0 kg, 20.0 ± 5.0% body fat) performed 30 continuous and dynamic jump squats (JS) and bench throws (BT) on 4 separate occasions. The movements were performed under loaded conditions utilizing 30% of subject's predetermined 1 repetition maximum in the back squat and bench press. Mean power (MP; W), peak power (PP; W), mean velocity (MV; $m\cdot s^{-1}$), peak velocity (PV; $m\cdot s^{-1}$), and total work (TW; J) were assessed using a ballistic measurement system (Innervations Inc., Muncie, IN). Data were analyzed using repeated measures analysis of variance with Duncan's post hoc test when mean differences were $p \leq 0.05$. Intraclass correlation coefficient (ICC) and within-subject coefficient of variation (CV%) were also calculated. All values are presented as mean ± *SE*. BT variables were statistically similar across the 4 sessions: MP (350.0 ± 13.9 W), PP (431.4 ± 18.5 W) MV (1.6 ± 0.03 $m\cdot s^{-1}$), PV (2.0 ± 0.03 $m\cdot s^{-1}$), and TW (199.1 ± 7.2 J). For JS, session 3 PP (1,669.8 ± 111.2 W) was significantly greater vs. sessions 1, 2, and 4 (1,601.2 ± 58.4 W). Session 4 MP (1,403.2 ± 88.6 W) and MV (1.9 ± 0.1 $m\cdot s^{-1}$) for JS were significantly lower during sessions 1, 2, and 3 (MP: 1,479.4.5 ± 44.8 W, MV: 2.0 ± 0.05 $m\cdot s^{-1}$). TW (834.7 ± 24.3 J) and PV (2.2 ± 0.04 $m\cdot s^{-1}$) were staistically similar during all sessions for JS. The CVs ranged from 3.0 to 7.6% for the BT and 3.2 to 5.7% for the JS. ICCs for MP, PP, MV, PV, and TW were 0.92, 0.95, 0.94, 0.91, and 0.95, respectively, during BT. ICCs during JS for MP, PP, MV, PV, and TW were 0.96, 0.98, 0.94, 0.94, and 0.89, respectively. The results of the current study support the use of a 30 continuous and dynamic BT protocol as a reliable upper-body physical performance test, which can be administered with minimal practice. Slightly greater variability for JS was observed, although the test had high reliability.

Key Words. intraclass correlation coefficients, power testing, squat jump, bench throw

Introduction

Many physical performance tests are available to quantify anaerobic performance, yet few of these tests assess mechanical power output during dynamic movements under near-optimal loaded conditions. Kaneko et al. (6), Moritani et al. (8), and Newton et al. (9, 10) have reported that training with 30% of a 1 repetition maximum (1RM) resulted in the greatest increase in maximal mechanical power output for upper and lower body. Training under these loading conditions can be referred to as near-optimally loaded conditions or dynamic weight training. These investigators illustrated the importance of testing under near-optimal loaded conditions, as maximal power output was attained at this prescribed load. Wilson et al. (19) developed a measurement system that allows for the accurate determination of power, velocity, force, acceleration, and work during dynamic, loaded movements. The development of this measurement system represented a major advance in the assessment of physical performance, as it allowed for instantaneous data collection during successive repetitions of dynamic, loaded, whole-body movements.

Quantifying muscular performance during repetitive movements may have greater relevance to success in real-world athletic and occupational activities when periods of physical activity last longer than several seconds or a few repetitions rather than a 1-time ballistic movement (i.e., vertical jump). Our laboratory has developed 2 dynamic ballistic power tests, 1 for the upper body and 1 for lower body. These tests require that subjects perform either 30 successive bench throws (BT) or jump squats (JS) at a load of 30% of their 1RM. Changes in performance tested under loaded conditions have been shown to be sensitive to such interventions as physical training (9, 16, 19), creatine supplementation (18), and military operational stress (12). In order for such tests to provide meaningful information, it is essential that data collected under these conditions be reliable. The practical significance of using highly reliable tests resides in the ability of such tests to detect small but significant changes in limited sample sizes (3, 4). Because motor learning and strategy development can occur during repeated practice sessions when performing unaccustomed movements, a test may need to be repeated a number of times before performance stabilizes and reliable, credible data can be obtained (3, 4, 14).

Therefore, the hypothesis of the current study was to examine if repeated sessions are necessary in order to obtain repeatable and reliable results during 30-repetition JS and BT. Reliability of power, force, and work during 30 repetitive and dynamic BT and JS movements performed with a load of 30% of each subject's 1RM for back squat and bench press was used to asses performance. A second purpose was to determine the minimum number of practice sessions that would be required before performance was stabilized on these tests.

Methods

Experimental Approach to the Problem

This study used a repeated measures design in which after preliminary baseline testing (body composition and maximal strength in the back squat and bench press), subjects visited the performance physiology laboratory on

4 separate occasions over a 2-week period. Each visit was separated by a minimum of 48 hours, and the subjects performed only 2 sessions each week. The order of testing (during 1 session) was to perform 30 repetitive JS and then, after a ~20–30-minute rest period, 30 repetitive BT. Thirty repetitions were chosen for the present study in order to allow evaluation across the spectrum of the anaerobic energy system (e.g., phosphogen system and anaerobic glycolysis). Additionally, 30 repetitions allowed the test to be modeled after the Wingate cycle ergometry test in terms of statistical evaluation (i.e., partitioning the data into 6 5-repetition blocks).

Warm-up included stretching, light aerobic exercise on a cycle ergometer, and 10 repetitions of each movement with an unloaded barbell. Dietary intake during the study was controlled by not allowing any supplement use and by requiring subjects to maintain their regular eating habits for the duration of the testing. Subjects were asked to refrain from participating in strenuous activity the day preceding testing. The data presented in this study were part of a larger study examining the effects of military operational stress on soldier physiology to which soldiers were exposed after the fourth session described herein (1, 11, 12, 14). For the 4 sessions reported here, all subjects were weight stable.

Subjects

Ten young, healthy male soldiers (22 ± 3 years, 1.83 ± 0.1 m, 87 ± 8 kg, 20 ± 5% body fat) volunteered for this experiment, which was approved by the Human Use Review and Scientific Review Committees at the U.S. Army Research Institute of Environmental Medicine (Natick, MA) and by the Human Subjects Research Review Board of its parent organization, the U.S. Army Medical Research and Materiel Command (Fort Detrick, MD). The investigators adhered to the policies for protection of human subjects as prescribed in Army Regulation 70-25, and the research was conducted in adherence with the provisions of 45 CFR Part 46. Subjects were medically screened, and written informed consent was obtained prior to study participation. These participants were in good physical condition and had graduated from basic combat training and advanced individualized training within the previous 6 months. During those periods of training, general calisthenics and running were the primary means of improving physical fitness. To our knowledge, participants had no prior history of participating in high-intensity resistance training.

Heights were obtained with an anthropometer (GPM, Seritex, Inc., Carlstadt, NJ). Body weight was measured with an electronic floor scale (Seca, Alpha model 770, Hamburg, Germany). Body composition measurements were obtained by dual energy X-ray absorptiometry by methods described elsewhere (12).

Maximal Strength

1RM in the back squat and bench press exercises were determined during preliminary testing. With the barbell placed on the shoulders, a successful parallel squat required descending by flexing the knees and hips until the proximal head of the femur reached the same horizontal plane as the superior border of the patella. The subject then returned to a standing position. For the 1RM bench press, the subject gripped the barbell slightly wider than shoulder width and lowered the barbell under control until it lightly touched the chest (i.e., without bouncing). The subject then lifted the barbell back to a straight-arm position while keeping the feet and hips in contact with the floor and bench. All strength testing was conducted on a MaxRack (Max Rack, Inc., Columbus, OH). Warm-up consisted of performing 5–10 repetitions at 40–60% of perceived maximum, a 3–5-minute rest and stretching period, and the completion of 3–5 repetitions at 60–80% of maximum. Three to 5 subsequent lifts were then made to determine the 1RM with 5 minutes of rest between lifts. An attempt was considered successful when the movement was completed through a full range of motion without deviating from proper technique and form. Spotters were present to provide verbal encouragement and safety for the subjects.

Physical Performance Tests

Continuous and dynamic BT and JS tests were used to measure upper- and lower-body physical performance, respectively. Subjects were required to perform 30 consecutive repetitions with a load equal to 30% of their predetermined 1RM. This load was chosen, as muscle power is maximized at 30% of maximal voluntary contraction (1, 6, 8, 19). All testing was performed in a ballistic manner on a MaxRack interfaced with a ballistic measurement system (Innervations Inc., Muncie, IN). The MaxRack is a machine analogous to the Smith machine. However, the Smith machine operates only in the vertical plane; the MaxRack allows the user to move the barbell in 3 dimensions. This adds a degree of safety as well as having the user work in an environment analogous to free weights.

For the BT, subjects laid supine on a bench with arms extended straight over the shoulders. Subjects lowered the barbell to the chest (at the area of the nipple) and were instructed to initiate the movement by throwing the barbell as high as possible at the end of the concentric movement. The subject caught the bar on its descent and immediately, without pause, initiated another maximal BT and continued doing this until 30 repetitions were completed. For the JS test, subjects squatted to a self-selected depth necessary for optimal vertical jump height, then jumped with the load as high as possible. After descent, the subjects, without pause, initiated another upward jumping movement and continued doing this until 30 repetitions were completed. Subjects were instructed to throw the barbell for maximal height for the BT and to jump for maximal height for the JS. For both the BT and the JS, participants self-selected hand placement on the barbell and self-selected foot placement and barbell placement for the JS. However, for the BT, participants were encouraged to place the hands at approximately slightly more than shoulder width apart. Participants during the JS were encouraged to place the feet approximately shoulder width apart and the barbell on the upper trapezius muscle and not the region of the cervical spine. However, no definitive anatomical locations were given to the participants regarding hand and foot placement during both of these tasks.

On the same day as 1RMs were determined and prior to collecting any ballistic power data, participants were allowed to perform ~5–10 JS and BT in an unloaded state to get the feel of the machine and to develop a kinesthetic sense of the body in the MaxRack as well as arm width and foot width for the BT and JS, respectively. During this familiarization process, subjects were instructed and

TABLE 1. Mean ± standard error (*SE*) values measured during sessions 1, 2, 3, and 4.*

Variable	Session 1	Session 2	Session 3	Session 4
Bench-throw				
Mean power (W)	355.3 ± 32.9	341.9 ± 32.6	347.2 ± 23.0	355.0 ± 25.5
Peak power (W)	433.6 ± 44.0	426.7 ± 40.6	429.8 ± 33.6	425.6 ± 34.4
Mean velocity ($m \cdot s^{-1}$)	1.7 ± 0.1	1.6 ± 0.1	1.6 ± 0.1	1.6 ± 0.1
Peak velocity ($m \cdot s^{-1}$)	2.3 ± 0.3	2.0 ± 0.1	2.0 ± 0.1	2.1 ± 0.1
Work (J)	205.2 ± 16.9	198.6 ± 14.6	195.8 ± 13.9	196.7 ± 14.2
Jump squat				
Mean power (W)	1,468.2 ± 77.5[a]	1,459.7 ± 85.2[a]	1,484.6 ± 73.7[a]	1,409.8 ± 79.5[b]
Peak power (W)	1,594.2 ± 101.9[a]	1,620.0 ± 106.9[a]	1,669.3 ± 99.5[b]	1,577.4 ± 95.1[a]
Mean velocity ($m \cdot s^{-1}$)	2.0 ± 0.1[a]	2.0 ± 0.1[a]	2.0 ± 0.1[a]	1.9 ± 0.1[b]
Peak velocity ($m \cdot s^{-1}$)	2.0 ± 0.1	2.2 ± 0.1	2.2 ± 0.1	2.1 ± 0.1
Work (J)	813.6 ± 45.0	861.2 ± 60.9	817.5 ± 44.8	846.5 ± 48.5

* Similar letters denote statistical similarity, while those with different letters denote those values that are statistically different ($p \leq 0.05$).

coached on how to perform the tests in a safe and an appropriate manner. The physical performance variables measured and used for analysis were mean power (W), peak power (W), mean velocity ($m \cdot s^{-1}$), peak velocity ($m \cdot s^{-1}$), and work (J). Spotters were present on both sides of the barbell for both the JS and the BT to provide verbal encouragement and ensure safety of the subjects.

Statistical Analyses

The results were analyzed with SAS statistical software (SAS Institute Inc., Cary, NC). Values from the different sessions were compared using a 1-way analysis of variance (ANOVA) with repeated measures. An alpha level of $p \leq 0.05$ was considered significant. When a significant session effect was detected, a pairwise comparison of the sessions was done using Duncan's multiple-range test (post hoc) to identify significant differences between sessions. Using variance estimates obtained through ANOVA, test-retest reliability of the sessions was determined using intraclass correlation coefficient (ICC) model 2, form 1 (14, 15):

$$ICC(2,1) = \frac{BMS - EMS}{BMS + (k - 1)EMS + \frac{k(RMS - EMS)}{n}}$$

where *BMS* is the between-subject's mean square variance, *EMS* is the error mean square, *RMS* is the between-test session's mean square, *k* is the number of test sessions, and *n* is the number of subjects tested. All sessions were compared to the first session to observe if reliability improved from session 1 (i.e., session 1 compared to session 2 [1-2], session 1 compared to session 3 [1-3], and session 1 compared to session 4 [1-4]). Additionally, Pearson product moment correlations were calculated for each respective anaerobic performance index between BT and JS. All data are presented as mean ± *SE*.

RESULTS

Table 1 displays the means for all performance variables for both BT and JS across sessions 1–4. All performance variables for the BT were statistically ($p > 0.05$) similar across all sessions. JS and BT were approximately 39 and 35 seconds in duration, respectively. JS mean power and mean velocity were statistically similar for sessions 1–3; however, session 4 was statistically lower than sessions 1–3. Peak power during sessions 1, 2, and 4 was statistically similar; however, session 3 was significantly ($p \leq 0.05$) greater than sessions 1, 2, and 4. Peak velocity and work for the JS were statistically similar across all 4 sessions.

TABLE 2. Intraclass correlation coefficients for session 1 to sessions 2, 3, and 4.

	Bench throw sessions			Jump squat sessions		
	1–2	1–3	1–4	1–2	1–3	1–4
Mean power (W)	0.88	0.99	0.93	0.96	0.95	0.89
Peak power (W)	0.92	0.93	0.96	0.96	0.96	0.94
Mean velocity ($m \cdot s^{-1}$)	0.93	0.92	0.95	0.96	0.97	0.89
Peak velocity ($m \cdot s^{-1}$)	0.95	0.92	0.91	0.84	0.89	0.93
Work (J)	0.87	0.92	0.85	0.73	0.80	0.93

TABLE 3. Coefficients of variation for both bench throw and jump squat.

	Bench throw	Jump squat
Mean power (W)	7.6%	4.4%
Peak power (W)	6.3%	3.2%
Mean velocity ($m \cdot s^{-1}$)	3.5%	3.4%
Peak velocity ($m \cdot s^{-1}$)	3.0%	3.4%
Work (J)	3.6%	5.7%

Table 2 lists the intraclass correlation coefficients (ICCs) for all performance variables for both BT and JS across sessions 1-2, 1-3, and 1-4, respectively. In general, after only 2 sessions, the performance data could be considered highly reliable as evidenced by ICCs > 0.90 (3–5). The ICCs did not demonstrate any significant differences from session 1-2 vs. 1-4. Table 3 lists the coefficients of variation (CV) for performance variables in the BT and JS. Table 4 lists the Pearson product moment correlation coefficients between the BT and JS performance variables, respectively. These correlations ranged from 0.46 to 0.76 (Table 4). In general, these correlations were only moderate, indicating that upper- and lower-body physical performances are not strongly associated. Figures 1 and 2 illustrate a subject performing a ballistic JS and BT, respectively. Figure 3 displays a representative fatigue curve for a BT and JS, respectively.

TABLE 4. Mean values for all 4 days of testing. *R* represents Pearson product moment correlations between composite averages of bench throw and jump squat.

Variable	Bench throw	Jump squat	*R*
Mean power (W)	348.9 ± 87.7	1,462.9 ± 239.6	0.66*
Peak power (W)	431.4 ± 116.8	1,615.3 ± 308.7	0.76*
Mean velocity ($m\cdot s^{-1}$)	1.6 ± 0.2	1.9 ± 0.3	0.46*
Peak velocity ($m\cdot s^{-1}$)	1.9 ± 0.2	2.2 ± 0.3	0.60*
Work (J)	199.1 ± 45.3	834.7 ± 153.9	0.48*

* Denotes statistical significance ($p \leq 0.05$).

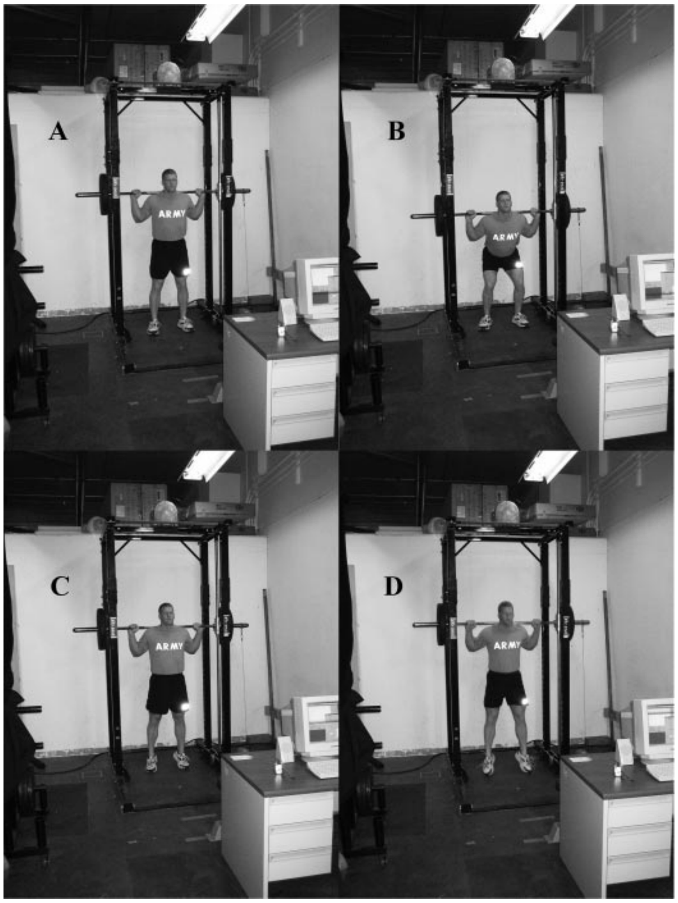

FIGURE 1. Subject performing jump squat: (a) standing position; (b) descent; (c) upward phase; (d) flight phase.

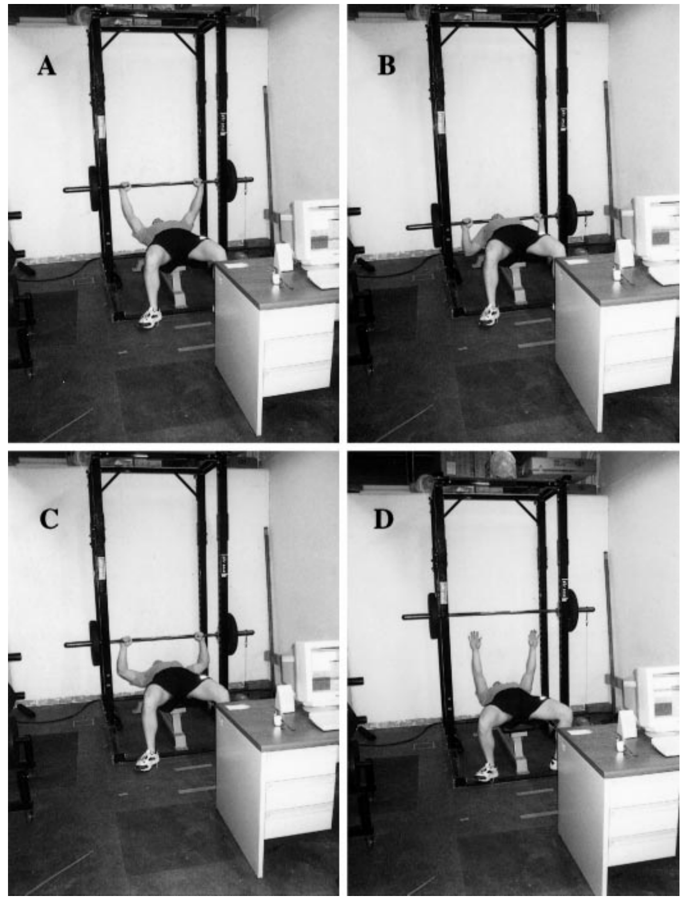

FIGURE 2. Subject performing bench throw: (a) standing position; (b) descent; (c) upward phase; (d) flight phase.

DISCUSSION

Assessment of physical performance during dynamic and repetitive muscle actions under loaded conditions has gained increasing popularity. More human performance laboratories are becoming equipped with ballistic measurement systems that allow accurate collection of indices related to physical performance. Measuring physical performance of movements under loaded conditions is based on the fundamental principles of the force-velocity power curve that dictate optimal power is generated under a specified range of loaded (i.e., force) parameters. Previous work has demonstrated that when 30% of a 1RM for a given load is used, maximal mechanical power output is attained (6, 8, 16, 19). Other studies have reported power outputs conducted with 30% 1RM loaded conditions ranging from 1 movement to 5 sets of 10 consecutive repetitions (6, 7, 9, 16, 18, 19). Thirty repetitions were chosen for the present study in order to allow evaluation across the spectrum of the anaerobic energy system (e.g., phosphogen system and anaerobic glycolysis). However, oxidative substrate contributions have been observed during short-term cycle ergometery sprinting of similar duration to the BT and JS in the current study (17). Anaerobic contributions have also been noted at and beyond $\dot{V}O_2max$, suggesting a continuum of substrate metabolism regardless of exercise intensity and duration (2, 17). This study demonstrates that the BT and JS tests developed by our laboratory are both highly reliable and require minimal, if any, practice before reproducible data can be obtained for analysis. For both BT and JS, performance between the first and second sessions showed strong agreement (i.e., were statistically similar with the ANOVA), the ICCs for the various indices ranged from 0.73 to 0.96, and the CVs ranged from 3.0 to 7.6%.

We find it somewhat notable that testing session 2 did not show a significant improvement over testing session 1 in any of the performance variables for either the BT or the JS. While jumping might be considered an elementary skill, jumping 30 consecutive times with a barbell loaded with 30% 1RM would certainly be considered an unconventional exercise with subjects having no prior experience with such an activity. The same would be true for the BT. We believe that the underlying basis of such consistency across testing sessions resides in the repetitive and singular nature of the movements. For example,

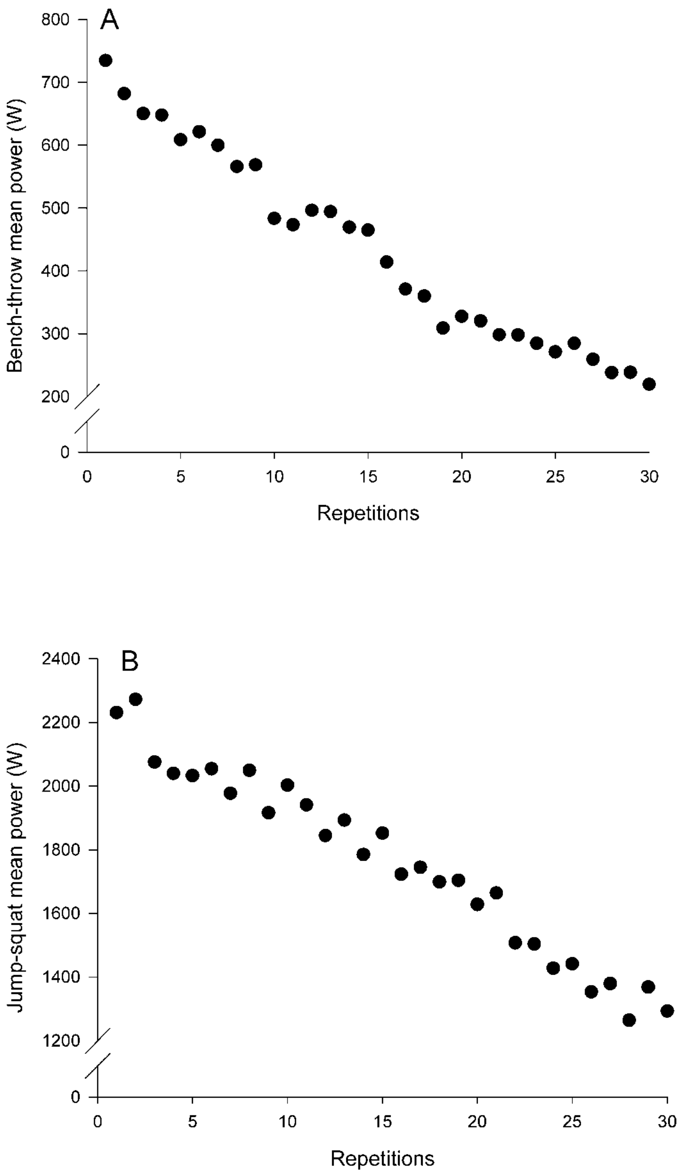

FIGURE 3. Representative fatigue curve of mean power for (a) the bench throw and (b) the jump squat.

we have recently reported that the number of practice sessions required before stabilizing performance in a 6-station obstacle course (consisting of hurdles, zigzag cones, low crawl, pole shimmy, wall jump, and sprint) was 4 sessions, while only 1 session was required for a 10-minute repetitive box lifting test involving essentially 1 movement (i.e., lifting a 45-pound box from the floor to a height of 1.32 m for 10 minutes) (14). In the present study, there was no evidence of a learning curve or changes in individual performance strategies between sessions 1 and 2, and we therefore conclude BT and JS to be reliable.

There were contrasts between performances of the BT and JS in terms of both correlations and variability across testing sessions. The correlations for the various performance indices ranged from 0.48 to 0.76, indicating only moderate associations. Nindl et al. (13) previously observed that upper- and lower-body anaerobic performance assessed by Wingate tests in adolescent athletes was also only moderately correlated. These findings imply that a certain degree of specificity exists regarding anaerobic power performance between the upper and lower body. Regional differences between the upper- and lower-body musculature in muscle fiber type, aerobic and anaerobic energy enzymes, and so on attributed to either genetic/hereditary and/or training history differences could contribute to such a lack of generalizability. The use of the JS and BT should be targeted specifically toward the musculature involved in the athlete's most important movements. These 2 physical performance tests could therefore not be used interchangeably.

The variability of the JS actually indicated a slight decrement in mean power and mean velocity during session 4 compared to sessions 1–3. The decrement in mean power (5.4%) and mean velocity (4.1%), while significant, was in close proximity to the CV. We are uncertain as to why this occurred, especially in light of the fact that power would exhibit increases with subsequent motor learning given more testing. The JS was performed with significantly heavier loads than the BT, and the overall work performed was greater than fourfold for the JS, thereby creating greater physiological strain. This result does suggest that excessive practice sessions for the JS should be avoided in order to eliminate the risk of potential performance declines in anaerobic performance.

PRACTICAL APPLICATIONS

Performance variables collected on the ballistic measurement system for the BT and JS were highly reliable over multiple sessions. Our data indicate that those who use the ballistic measurement system may gather reliable results during anaerobic performance data after only 1 session. This finding is important for strength and conditioning coaches who must logistically manage the collection of tests for large numbers of athletes. It is critical that the detection of changes in performance be truly due to performance changes and not due to "learning curves." A learning curve is not apparent for BT and JS when performed for 30 repetitions with a load of 30% 1RM. Despite our data indicating that practice sessions are not a necessity, we do recommend subjects perform at least 1 practice session before data collection to alleviate any potential concerns regarding the exercise technique or safety of the subject.

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