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Comparison of High-Volume and High-Intensity Upper Body Resistance Training on Acute Neuromuscular Performance and Ratings of Perceived Exertion

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ABSTRACT

International Journal of Exercise Science 13(1): 723-733, 2020. The assessment of neuromuscular fatigue is important for minimizing the risks of nonfunctional overreaching, and monitoring training loads has rapidly grown in recent years. The objective of the study was to compare the acute upper body performance and rating of perceived exertion (RPE) responses to high-volume (HV) and high-intensity (HI) resistance-training loads. Sixteen young resistance-trained men (4 repetition maximum [RM] bench press = 105.8 ± 15.9 kg) were divided into two groups of eight subjects each that performed a HI (3 sets of 4RM with 180 s of rest), and a HV (4 sets of 12RM with 90 s of rest) training sessions. Session RPE was obtained 30 min Post. The medicine-ball throw (MBT) performance was measured at pre, and 10 min post. Training volume load (movements × load), and intensity (volume load ÷ movements) were calculated. Volume load was significantly higher for HV (10890 ± 1241 kg) than HI (2718 ± 413 kg) protocol ($p < 0.001$). Intensity was significantly higher for HI (100.7 ± 15.3 kg) than HV (75.6 ± 8.6 kg) protocol ($p = 0.002$). MBT performance was significantly reduced from pre- to post- HV ($p < 0.001$; $\Delta = -11\%$), but not in HI ($p = 0.15$; $\Delta = -5\%$). RPE was significantly higher Post-HI (9.9 ± 0.4) than Post HV (8.9 ± 0.8) ($p = 0.01$). We conclude that higher volume loads induce greater upper body neuromuscular fatigue in young resistance-trained men. Session RPE may reflect training intensity, but not the performance impairments.

KEY WORDS: Neuromuscular fatigue, monitoring training loads, internal load, neuromuscular power, volume load

INTRODUCTION

The effectiveness of traditional resistance-training programs to achieve a specific training physiological, neuromuscular and functional response (i.e. muscular endurance, hypertrophy, maximal strength, or power) depends on the manipulation of training load variables (4, 24).

Load progressions are typically performed by recording the load lifted, the total number of repetitions completed, and the calculation of volume load (movements × load), and intensity (volume load ÷ movements) has been frequently used to monitor athletes (6). The literature emphasizes that monitoring and quantifying training loads is a vital step to understand neuromuscular fatigue and the acute metabolic and mechanical stress imposed by the training (18). The process may be implemented to try to reduce the risk of injury, illness, and nonfunctional overreaching and allows the identification of athletes who are not responding to the training program (18).

External training loads are objective measures of the work performed by the athlete during training or competition (6). Alternatively, internal loads are accessed through the use of ratings of perceived exertion (RPE) (6). Internal load monitoring can determine the appropriate stimulus for optimal adaptations (12, 35) by monitoring physiological stress, or an athlete's perceived effort (18). Ratings of perceived excretion are also often combined with other variables such as session duration and heart-rate (6, 18). While the use of internal load monitoring has grown in popularity (23, 27), few studies have compared the internal load of different resistance-training programs in a homogeneous population (13). Furthermore, some of the protocols present in the literature do not represent a maximal strength regimen that would be adopted by elite athletes (16).

Although considered the gold standards for measuring variables associated with strength and power, instruments like the force platform and linear position transducers can be difficult to work with and are beyond the budget of many strength and conditioning professionals. Alternatively, field tests such as vertical or horizontal jumps (11, 21), medicine ball throws (MBT) (36), plyometric pushups (38), and maximal lifting (21) have been demonstrated to be practical, reliable, and valid tools to analyze neuromuscular fatigue, and the time-course of post-training recovery.

Much of the existing literature has demonstrated significant neuromuscular fatigue (observed by decrements in isometric and dynamic strength, peak force, rate of force development, and power output) following both high-volume (HV) and low-volume (HI) resistance-training protocols (28, 31, 37). The quantification of acute neuromuscular fatigue induced by distinct training loads would aid in understanding observed chronic adaptations resulting from resistance-training programs. This improved knowledge could be applied to the optimal organization of the training programs (37). Specific neuromuscular fatigue characteristics may be associated with the application of the external loads. Although, as this quantification does not always directly reflects the biological stress imposed, the internal load's measurements become more relevant during the training process (12, 35).

The objectives of the present study were to compare acute upper body performance and RPE responses to HV and HI resistance-training. Due to the higher mechanical stress imposed on the neuromuscular system, we hypothesized that the HV protocol would induce greater neuromuscular fatigue, while the HI protocol would potentiate performance. Similarly, it was also hypothesized that the HV protocol would lead to greater RPE.

METHODS

Participants

Sixteen young resistance-trained men volunteered to participate in this study and were randomly divided into two groups via an Excel (Microsoft, Redmond, WA) randomization spreadsheet (Table 1). Subject's exclusion criteria were smoking history during the last three months, presence of cardiovascular or metabolic disease, systemic hypertension (≥ 140/90 mmHg or use of anti-hypertensive medication), creatine supplementation in the last eight weeks, use of androgenic anabolic steroids, drugs or medications with potential impact in physical performance, and recent musculoskeletal injuries the could compromise the performance of test and training protocols. The study procedures were approved by the local institutional Ethical Committee for Human Experiments in accordance with the Declaration of Helsinki. Additionally, all subjects signed an informed consent form before data collection. All methods conform to the ethical standards of the International Journal of Exercise Science (30).

Table 1. Subject characteristics.

Variables	High-volume (n = 8)	High-intensity (n = 8)
Age (years)	25.7 ± 2.9	29.1 ± 3.3
Body mass (kg)	86.2 ± 4.7	80.5 ± 6.8
Height (m)	1.78 ± 0.0	1.77 ± 0.1
BMI (kg/m^2)	27.2 ± 1.7	25.8 ± 1.4
4 RM bench press (kg)	106.2 ± 15.1	105.4 ± 17.6
12 RM bench press (kg)	81.3 ± 8.3	77.8 ± 9.9
Resistance-training background (years)	7.1 ± 3.9	9.1 ± 4.8
Resistance-training frequency (days per week)	5.3 ± 0.5	5.1 ±0.4

Note. BMI = body mass index. Data present as mean ± standard deviation.

Protocol

The present study was a cross-sectional randomized controlled trial design. Volunteers were randomly split into either a HV (n = 8) or HI (n = 8) upper-body exercises group. Pre- to post-exercise responses were evaluated via session RPE and a seated MBT performance test. The MBT performance, 4 and 12 repetition maximum (RM) loads for the bench press exercise were assessed through test and retest sessions before the first experimental session.

Participants visited the lab on three separate days 48 hours apart. During the first visit, the participants underwent basic anthropometric measurements and were familiarized with the RPE measure, and the tests to find individual MBT distances and 4RM and 12RM bench press loads. The MBT and 4RM and 12RM tests were performed in the second visit to determine test-retest reliability. During the third visit, the HI or HV resistance protocols were performed. Ten min post either training protocols, the MBT was performed. Session RPE was assessed 20 min post MBT test (30 min post-training). Figure 1 presents the experimental design of the study.

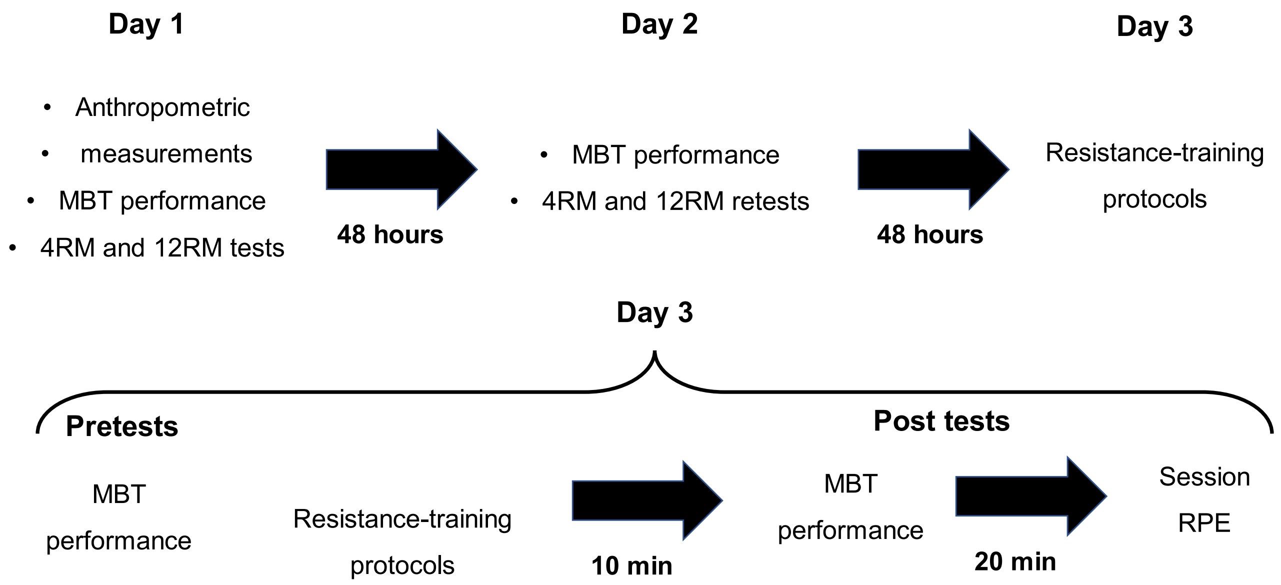

Figure 1. General experimental design of the study. MBT = medicine ball throw; RM = repetitions maximum.

The MBT performance test was conducted following a warm-up, consisting of three submaximal throws, the maximal distance was measured following the procedures recommended by Harris et al. (19). The subjects were instructed to sit on the floor with their head, shoulders, and lower back against a wall and throw a 3-kg rubber medicine ball as far as possible without the head, shoulders, and hips leaving the wall. One minute of passive rest followed each throw. The three trials were recorded and averaged before analysis.

The resistance-training protocols consisted of a high-volume (HV; 4 sets of 12RM, with 90 seconds of rest between sets) or high-intensity (HI; 4 sets of 4RM, with 180 seconds of rest between sets) performed in the bench, incline and decline press. Warm-up of 4RM and 12RM bench press tests were gradually progressed from light to moderate loads with three minutes of rest between sets (7). Following the warm-up, subjects were first tested for their 4RM load, and 10 minutes post passive rest, they performed a 12RM test. No more than three attempts were needed for load establishment, with three minutes of rest given between each attempt. The prescription of intensity for the bench press, incline press, and decline press were all based on the loads obtained during the 4RM and 12RM bench press assessments. Incline and decline press loads adopted were 10% lower than the bench press. During the sessions, the researchers involved in the study provided a standardized level of vigorous verbal encouragement. In the case of fatigue leading to concentric failure, a researcher provided enough upwards force to the barbell to ensure that the minimum number of repetitions were completed.

The CR-10 category RPE scale was used to rate the entire workout. Subjects were shown the scale 30 minutes following the conclusion of each protocol and asked: "How was your workout?" (14). The external loads (volume load and training intensity) were determined according to the procedures proposed by Haff (17). Equations 1 and 2 were employed to calculate the parameters (17).

Equation 1: Volume load (kg) = movements x loads (kg)

Equation 2: Intensity (kg) = Volume load / movements

Statistical Analysis

Data distribution was checked by the D'Agostino & Pearson test. With the exception of the volume load, all data were considered as normal by analyzing residuals using QQ plots. An independent samples t-test with Welch´s correction was used to analyze RPE and training intensity between groups. Volume load was analyzed with independent samples Mann-Whitney test. A two-way analysis of variance (ANOVA) with Tukey's post-hoc was employed to compare the MBT performance at pre-and post-moments. Cohen's d effect sizes (ES) were calculated to determine the magnitude of practical effect of the performance variables (10). The magnitude of the ES was classified according to the scale proposed by Rhea (33) to highly trained individuals (training for at least 5 years): trivial (< 0.25), small (> 0.25–0.5), moderate (0.5–1.0), large (> 1.0). MBT test re-test reliability was evaluated by the intraclass coefficient of correlation ($ICC_{3,1}$) and the coefficient of variation (CV). All data are presented as the mean ± standard deviation (SD), and the statistical significance was set at 5%. Post-hoc statistical power was determined using G*Power (Düsseldorf, Germany). Statistical analyses and figure constructions were performed using GraphPad Prism version 8.3.0 for Windows (GraphPad Software, San Diego, California USA).

RESULTS

Achieved statistical power for the main effect of MBT performance (pre = 3.62 ± 0.43 m; post = 3.31 ± 0.37 m) was $\beta = 0.901$, based on $p = 0.05$, ES = 0.77 and $N = 16$. Test re-test of the MBT was highly reliable (ICC = 0.96 and CV = 9.5-9.9).

No significant differences were observed between groups and moments for the absolute values of the MBT performance changes. However, ES was classified as moderate and normalized data analysis presents a significant (-11.6 ± 5.6%; $p < 0.001$) reduction from pre- to post-HV protocol – see Figure 2. Session RPE was significantly higher post HI (9.9 ± 0.3) than HV (8.9 ± 0.8) protocol ($p = 0.012$) – see Figure 3.

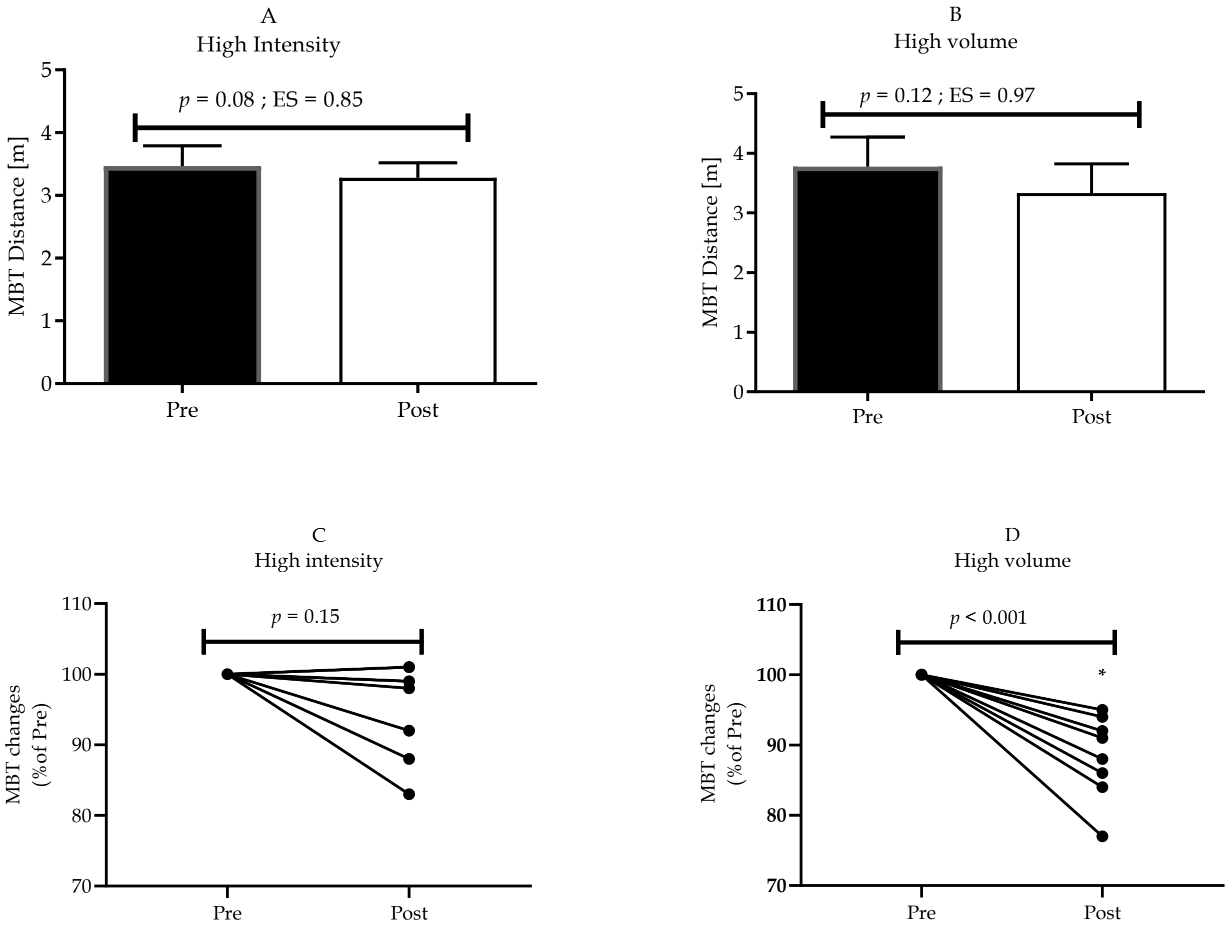

Figure 2. MBT performance responses to HI (A) and HV (B) training protocols. Figures C and D presents the % changes in MBT performance post-HI (C) and post-HV (D). *Significant difference to HV protocol. Data present as mean ± standard deviation.

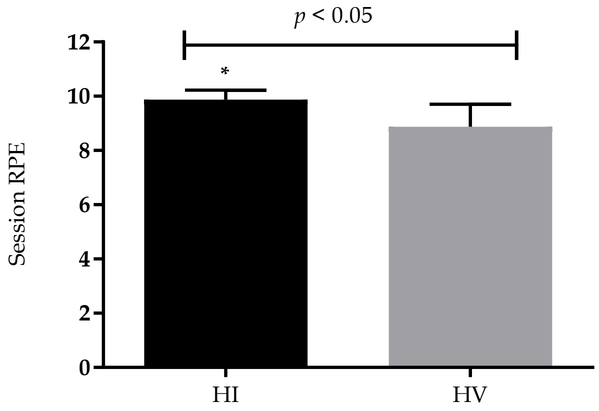

Figure 3. Rating of perceived exertion (RPE). *Significant difference to HV protocol.

Volume load was significant higher for HV (10890 ± 1241 kg) than HI (2718 ± 413 kg) protocol ($p < 0.001$). On the other hand, training intensity was significantly higher for HI (100.7 ± 15.3 kg) than HV (75.6 ± 8.6 kg) protocol ($p = 0.002$). Figure 4 presents the external loads of each resistance-training protocol.

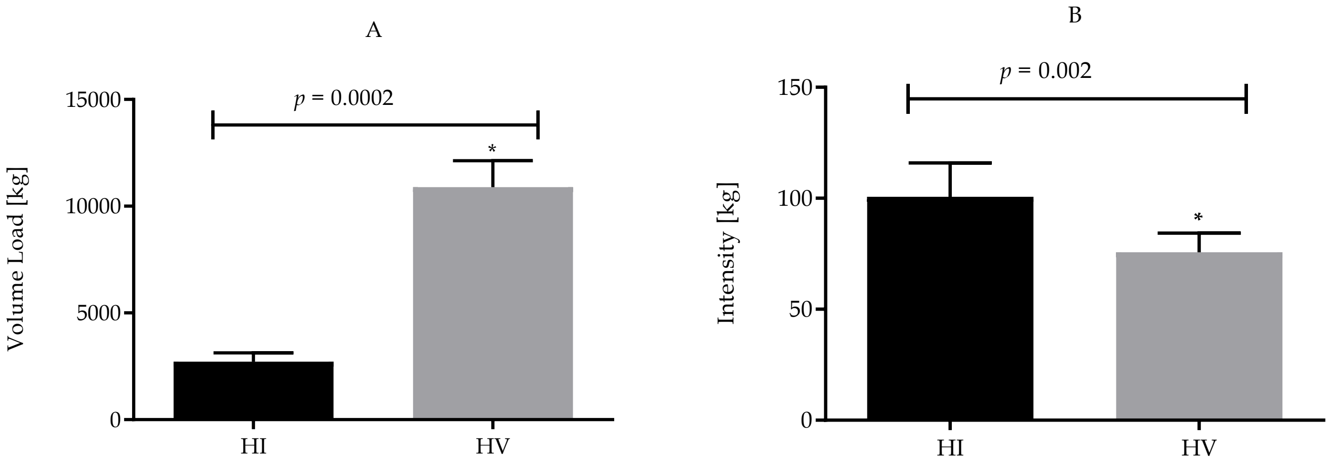

Figure 4. Volume load (A) and intensity (B) of the resistance-training protocols. *Significant difference to HI protocol. Data present as mean ± standard deviation.

DISCUSSION

The objective of the study was to compare the acute upper body performance and RPE responses to HV and HI resistance-training loads. The main results observed were that MBT performance presented a significant decrease post-HV protocol. However, session RPE was significantly higher post-HI when compared to the HV protocol. Therefore, our hypothesis that the HV protocol would induce greater fatigue was confirmed.

Our results are in agreement with the body of literature demonstrating that neuromuscular performance is negatively affected by HV protocols (28, 31, 37). However, methodological differences between the current study and the existing literature make comparisons difficult. Previous studies compare acute neuromuscular fatigue between loading protocols where strength or hypertrophy are desired outcomes, have demonstrated a decrease in isometric strength immediately and 15 min after exercise regardless of protocol (28, 37). Although a simple test was used to investigate similar variables in the current study, the MBT, as well as jump tests are reliable tools to measure neuromuscular response after exercise (9, 36).

Neuromuscular fatigue is a multifaceted issue with various contributing factors (1). This phenomenon is multifactorial, reversible, with magnitude dependent on the specificity of the tasks performed (5, 8, 21). From our methodology, we cannot say which sources, or what proportion of fatigue is central or peripheral without far-reaching assumptions. The literature has shown that high-volume protocols produce a greater amount of peripheral fatigue when compared to high-intensity protocols (37). Nevertheless, the exact causes of peripheral fatigue are difficult to determine. Factors such as decreased phosphocreatine and glycogen concentration, intramuscular pH level, increase inorganic phosphates, calcium, reactive oxygen species, and muscle damage, play a large role in the reduced ability to produce force (1). For example, Sanchez-Medina and Gonzalez-Badillo (34) compared the effects of the bench press and squat sets performed with a variety of loads and set/repetition schemes. The most relevant findings to the current study were that blood lactate ($8.9\ \text{mmol}\cdot\text{L}^{-1}$ vs. $4.9\ \text{mmol}\cdot\text{L}^{-1}$), and ammonia ($111\ \text{mmol}\cdot\text{L}^{-1}$ vs. $53\ \text{mmol}\cdot\text{L}^{-1}$) were significantly higher following 3 sets of bench press at 12RM when compared to 3 sets of 4RM (34). In agreement with our study, Sanchez-Medina and Gonzalez-Badillo (34) also reported greater reductions in neuromuscular output, assessed as velocity loss, following their 12RM versus 4RM protocol. However, it should be noted that in the current study, the MBT was performed 10 min after training; a period that has been demonstrated to sufficiently restore phosphocreatine concentration, but not other factors related to performance impairment (2, 31).

Regarding RPE, contradictory results have been observed. While some studies demonstrate that RPE is more dependent on total work than relative intensity (25), others have found that RPE is influenced to a greater degree by exercise intensity (12, 29). Our findings give support to the latter premise, where intensity exerts a greater influence on RPE than volume (Figure 3); though the RPE response constitutes the integration of multiple perceptual and physiological cues (metabolic acidosis, variation in muscle volume recruited, muscle load, etc.) (20, 29). With higher exercise intensity, greater force is required; consequently, more motor units may be recruited (15). Furthermore, the subjects had notable resistance-training experience (7.1 ± 3.9 years), were well trained, and accustomed to HV protocols. All of which must be taken into consideration when analyzing RPE results and comparing it to other populations.

One of the main limitations of our study is that we did not utilize a cross-over study design, which would have been valuable in strengthening or refuting our findings. Additionally, we did not use any gold standard instruments (e.g. force platforms, load cells) to quantify changes in neuromuscular performance as the peak force and rate of force development. Nevertheless, the MBT is a reliable, practical, low cost, and safe test for evaluating explosive power (19). It should also be noted that while we determined that RPE was not a suitable measure for monitoring fatigue in our study, only a single familiarization session was provided to our participants. However, a great deal of research supports the use of session RPE, but not necessarily for short bouts of resistance-training (22, 23, 26, 27). It would have been interesting to include a time course of recovery by having the participants perform the MBT (or other neuromuscular evaluations) at several time-points following each protocol (2, 3, 32). Additionally, we did not counterbalance our 4RM and 12RM assessments, leading to the possibility that additional fatigue would be accumulated before the 12RM test. Finally, the sample size of 16 participants (8 per group) is relatively small. As such our results should be interpreted with caution.

In conclusion, the HV protocol results in a greater reduction in the MBT test performance when compared to the HI protocol. Practitioners should be aware that higher volumes of upper-body pressing lead to greater neuromuscular fatigue, and therefore, larger acute performance reductions when compared to lower volumes of high-intensity exercise. Therefore, athletes and coaches should avoid high volumes of upper-body exercises when high levels of neuromuscular power output are required in the short term. Session RPE was also unable to monitor fatigue in young resistance-trained men.

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REFERENCES

1. Allen DG, Lamb GD, Westerblad H. Skeletal muscle fatigue: Cellular mechanisms. *Physiological Reviews* 88(1): 287-332, 2008.

2. Baker D. Acute negative effect of a hypertrophy-oriented training bout on subsequent upper-body power output. *J Strength Cond Res* 17(3): 527-530, 2003.

3. Baker D, Newton RU. The deleterious acute effects of the high volume-load german volume training workout upon upper body power output. *J Aust Strength Cond* 17(2): 11-19, 2009.

4. Bird SP, Tarpenning KM, Marino FE. Designing resistance training programmes *Sports Med* 35(10): 841-851, 2005.

5. Bishop PA, Jones E, Woods AK. Recovery from training: a brief review: brief review. *J Strength Cond Res* 22(3): 1015-1024, 2008.

6. Bourdon PC, Cardinale M, Murray A, Gastin P, Kellmann M, Varley MC, Gabbett TJ, Coutts AJ, Burgess DJ, Gregson W, Cable NT. Monitoring Athlete Training Loads: Consensus Statement. *Int J Sports Physiol Perform* 12(Suppl 2): S2161-S2170, 2017.

7. Brown LE, Wier JP. ASEP Procedures recommendation I: Accurate assessment of muscular strength and power. *Journal of Exercise Physiology Online* 4(3): 1-21, 2001.

8. Chapman D, Newton M, Sacco P, Nosaka K. Greater muscle damage induced by fast versus slow velocity eccentric exercise. *Int J Sports Med* 27(8): 591-598, 2006.

9. Claudino JG, Cronin J, Mezencio B, McMaster DT, McGuigan M, Tricoli V, Amadio AC, Serrao JC. The countermovement jump to monitor neuromuscular status: A meta-analysis. *J Sci Med Sport* 20(4): 397-402, 2017.

10. Cohen J. *Statistical Power Analysis for the Behavioural Sciences.* Hillsdale, NJ: Lawrence Erlbaum Associates, 1988.

11. da Silva BVC, Ide BN, Simim MAM, Marocolo M, Mota GRd. Neuromuscular responses to simulated Brazilian Jiu-Jitsu fights. *J Hum Kinet* 44(1): 249-257, 2014.

12. Day ML, McGuigan MR, Brice G, Foster C. Monitoring exercise intensity during resistance training using the session RPE scale. *J Strength Cond Res* 18(2): 353-358, 2004.

13. Egan AD, Winchester JB, Foster C, McGuigan MR. Using session RPE to monitor different methods of resistance exercise. *J Sports Sci Med* 5(2): 289-295, 2006.

14. Foster C, Florhaug JA, Frankin J, Gottschall L, Hrovatin LA, Sarker S. A new approach to monitoring exercise training. *J Strength Cond Res* 15(1): 109-115, 2001.

15. Gearhart RJ, Goss FL, Lagally KM, Kakicic JM, Gallagher J, Gallager KI, Robertson RJ. Ratings of perceived exertion in active muscle during high-intensity and low-intensity resistance exercise. *J Strength Cond Res* 16(1): 87-91, 2002.

16. Gonzalez AM. Acute anabolic response and muscular adaptation after hypertrophy-style and strength-style resistance exercise. *J Strength Cond Res* 30(1): 2959-2964, 2016.

17. Haff GG. Quantifying workloads in resistance training: A brief review. *UK Strength and Conditioning Association*: 30-39, 2010.

18. Halson SL. Monitoring training load to understand fatigue in athletes. *Sports Med* 44(Suppl 2): S139-147, 2014.

19. Harris C, Wattles AP, DeBeliso M, Sevene-Adams PG, Berning JM, Adams KJ. The seater medicine ball throw as a test of upper body power in older adults. *J Strength Cond Res* 25(8): 2344-2248, 2011.

20. Hollander DB, Kilpatrick MW, Ramadan ZG, Reeves GV, Francois M, Blakeney A, Castracane VD, Kraemer RR. Load rather than contraction type influences rate of perceived exertion and pain. *J Strength Cond Res* 22(4): 1184-1193, 2008.

21. Ide BN, Leme TC, Lopes CR, Moreira A, Dechechi CJ, Sarraipa MF, Da Mota GR, Brenzikofer R, Macedo DV. Time course of strength and power recovery after resistance training with different movement velocities. *J Strength Cond Res* 25(7): 2025-2033, 2011.

22. Jakobsen MD, Sundstrup E, Persson R, Andersen CH, Andersen LL. Is Borg's perceived exertion scale a useful indicator of muscular and cardiovascular load in blue-collar workers with lifting tasks? A cross-sectional workplace study. *Eur J Appl Physiol* 114(2): 425-434, 2014.

23. Johnston RD, Black GM, Harrison PW, Muray NB, Austin DJ. Applied sport science of Australian Football: A systematic review. *Sports Med* 48(7): 1673-1694, 2018.

24. Kraemer WJ, Ratamess NA. Fundamentals of resistance training Progression and exercise prescription. *Med Sci Sports Exerc* 36(4): 674-688, 2004.

25. Kraft JA, Green JM, Thompson KR. Session ratings of perceived exertion responses during resistance training bouts equated for total work but differing in work rate. *J Strength Cond Res* 28(2): 540-545, 2014.

26. Mays RJ, Goss FL, Nagle EF, Gallagher MJ, Haile L, Schafer MA, Kim KH, Robertson RJ. Cross-validation of peak oxygen consumption prediction models From OMNI perceived exertion. *Int J Sports Med* 37(10): 831-837, 2016.

27. McCall A, Jones M, Gelis L, Duncan C, Ehrmann F, Dupont G, Duffield R. Monitoring loads and non-contact injury during the transition from club to National team prior to an international football tournament: A case study of the 2014 FIFA World Cup and 2015 Asia Cup. *J Sci Med Sport* 21(8): 800-804, 2018.

28. McCaulley GO, McBride JM, Cormie P, Hudson MB, Nuzzo JL, Quindry JC, Triplett NT. Acute hormonal and neuromuscular responses to hypertrophy, strength and power type resistance exercise. *Eur J Appl Physiol* 105(5): 695-704, 2009.

29. McGuigan MR, Egan AD, Foster C. Salivary cortisol responses and perceived exertion during high intensity and low intensity bouts of resistance exercise. *J Sports Sci Med* 3(1): 8-15, 2004.

30. Navalta JW, Stone WJ, Lyons ST. Ethical issues relating to scientific discovery in exercise science. *Int J Exerc Sci* 12(1): 1-8, 2019.

31. Nicholson G, McLoughlin G, Bissas A, Ispoglou T. The effect of training volume and intensity on improvements in muscular strength and size in resistance-trained men. *J Strength Cond Res* 28(1): 3188-3199, 2014.

32. Pareja-Blanco F, Rodríguez-Rosell D, Sánchez-Medina L, Ribas-Serna J, López-López C, Mora-Custodio R, Yáñez-García JM, González-Badillo JJ. Acute and delayed response to resistance exercise leading or not leading to muscle failure. *Clin Physiol Funct Imaging* 37(6): 630-639, 2017.

33. Rhea MR. Determining the magnitude of treatment effects in strength training research through the use of the effect size. *J Strength Cond Res* 18(4): 918-920, 2004.

34. Sanchez-Medina L, Gonzalez-Badillo JJ. Velocity loss as an indicator of neuromuscular fatigue during resistance training. *Med Sci Sports Exerc* 43(9): 1725-1734, 2011.

35. Scott BR, Duthie GM, Thornton HR, Dascombe BJ. Training monitoring for resistance exercise: Theory and applications. *Sports Med* 46(5): 687-698, 2016.

36. Simin M, Bradley P, Da Silva B, Mendes E, De Mello M, Marocolo MJ, da Mota GR. The quantification of game-induced muscle fatigue in amputee soccer players. *J Sports Med Phys Fitness* 57(6): 766-772, 2017.

37. Walker S, Davis L, Avela J, Hakkinen K. Neuromuscular fatigue during dynamic maximal strength and hypertrophic resistance loadings. *J Electromyogr Kinesiol* 23(3): 356-362, 2012.

38. Wang R, Hoffman JR, Sadres E, Bartolomei S, Muddle TWD, Fukuda DH, Stout JR. Evaluating upper-body strength and power from a single test: The ballistic push-up. *J Strength Cond Res* 31(5): 1338-1345, 2017.