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RELIABILITY OF THE ONE REPETITION-MAXIMUM POWER CLEAN TEST IN ADOLESCENT ATHLETES

Avery D. Faigenbaum¹, James E. McFarland², Robert Herman², Fernando Naclerio³, Nicholas A. Ratamess¹, Jie Kang¹, and Gregory D. Myer⁴

¹The College of New Jersey, Department of Health and Exercise Science, Ewing, NJ

²Hillsborough High School, Hillsborough, NJ

³Universidad Europea de Madrid, Madrid, Spain

⁴Cincinnati Children's Hospital Medical Center, Cincinnati, OH

Abstract

Although the power clean test is routinely used to assess strength and power performance in adult athletes, the reliability of this measure in younger populations has not been examined. Therefore, the purpose of this study was to determine the reliability of the one repetition maximum (1 RM) power clean in adolescent athletes. Thirty-six male athletes (age 15.9 ± 1.1 yrs, body mass 79.1 ± 20.3 kg, height 175.1 ± 7.4 cm) who had more than 1 year of training experience with weightlifting exercises performed a 1 RM power clean on two nonconsecutive days in the afternoon following standardized procedures. All test procedures were supervised by a senior level weightlifting coach and consisted of a systematic progression in test load until the maximum resistance that could be lifted for one repetition using proper exercise technique was determined. Data were analyzed using an intraclass correlation coefficient (ICC [2,k]), Pearson correlation coefficient (r), repeated measures ANOVA, Bland-Altman plot, and typical error analyses. Analysis of the data revealed that the test measures were highly reliable demonstrating a test-retest ICC of 0.98 (95% CI = 0.96–0.99). Testing also demonstrated a strong relationship between 1 RM measures on trial 1 and trial 2 ($r=0.98$, $p<0.0001$) with no significant difference in power clean performance between trials (70.6 ± 19.8 vs. 69.8 ± 19.8 kg). Bland Altman plots confirmed no systematic shift in 1 RM between trial 1 and trial 2. The typical error to be expected between 1 RM power clean trials is 2.9 kg and a change of at least 8.0 kg is indicated to determine a real change in lifting performance between tests in young lifters. No injuries occurred during the study period and the testing protocol was well-tolerated by all subjects. These findings indicate that 1 RM power clean testing has a high degree of reproducibility in trained male adolescent athletes when standardized testing procedures are followed and qualified instruction is present.

Keywords

Weightlifting; strength training; children; youth; fitness testing

INTRODUCTION

Resistance training has consistently demonstrated to be a safe and effective mode of exercise for children and adolescents provided that age-appropriate training guidelines are followed

and qualified instruction is available (10, 25). Current public health objectives now aim to increase the number of school-age youth who participate in muscle strengthening activities and the qualified acceptance of youth resistance training by medical and fitness organizations is becoming universal (3, 9, 23, 29). However, methods for evaluating strength and power in younger populations remain controversial. Although one repetition maximum (1 RM) testing is supported by the National Strength and Conditioning Association (NSCA) and has been used by researchers to assess muscular fitness in healthy children and adolescents (7, 9, 15, 31), some observers remain opposed to maximal lifting in younger populations because of the presumption that high intensity loading may cause structural damage (2). These differing views reported in the literature have resulted in ambiguity surrounding the issue of strength and power testing in youth. Moreover, little is known about the reliability of muscular fitness testing in young lifters.

In adult athletes, test criteria such as the 1 RM power clean are routinely used to develop individualized programs and assess the effectiveness of a training cycle (16, 20). The 1 RM power clean assessment is unique because it can be used to test strength and power. Unlike traditional resistance exercises such as the bench press and back squat that are performed at a relatively low movement speed, the power clean is an explosive but highly-controlled movement that is performed at a maximal movement speed. In the power clean exercise, a barbell is lifted from the platform to the shoulders in a single, continuous, forceful movement. Success with the power clean exercise involves complex and synchronized neural recruitment patterns and may provide a better impression of an athlete's whole body power relative to other resistance exercises. Accordingly, some experts hypothesize that power clean performance may be directly associated with sport related power (7, 19). In adult athletes, the power clean test provides a highly reliable measure of maximum muscular power (21, 33). To our knowledge, no similar data exist which evaluate the reliability, validity or safety of such testing with power clean movements in adolescent athletes. Given the link between power training and sports performance, it is paramount that pediatric researchers and youth coaches establish the reliability of power testing in youth.

The assessment of maximal muscular power is one of the most important determinants of athletic performance (7, 11, 19). While field tests such as the standing long jump and vertical jump are typically used to assess anaerobic power in younger populations (6, 22, 28), weightlifting movements such as the power clean are perhaps the best measure of combined whole body strength and power (14, 19). During the performance of the power clean the lifter must initially exert high forces to accelerate the barbell through the entire range of pulling without actively decelerating the barbell.

While our laboratory has examined the safety, efficacy and reliability of 1 RM strength testing in children (12, 13, 22), an assessment of maximal power clean testing remains unexplored in younger populations. In order for the 1 RM power clean to provide meaningful information to youth coaches and pediatric researchers, it is important to perform a reliability assessment of this measure in young lifters. Information pertaining to the reliability of 1 RM testing in younger populations is vital for the accurate assessment of training outcomes as well as the replication of research experiments. This information is particularly important relative to the updated NSCA position statement paper on youth resistance training that supports maximal lifting in younger populations provided age-appropriate guidelines are followed (9). Hence, the aim of the present investigation was to assess the reliability of the 1 RM power clean in a group of adolescent athletes.

METHODS

Experimental Approach to the Problem

In this study, we assessed the reliability of the 1 RM power clean in trained adolescents who had experience performing weightlifting exercises. Subject's performed the 1 RM power clean on two non-consecutive test sessions (3–7 days apart) at the same time of day (late-afternoon). Test procedures were administered by a USA weightlifting senior level coach and consisted of a systematic progression in test load until the maximum resistance that could be lifted for one repetition using proper exercise technique was determined. This approach allowed us to carefully monitor the response of each subject to the testing protocol, individually evaluate 1 RM performance, and assess the reliability of power clean testing in young lifters.

Subjects

The methods and procedures used in this study were approved by the Institutional Review Board for use of human subjects at the College, and informed consent was obtained from all parents and assent was obtained from each subject prior to participation. Thirty-six male athletes (age 15.9 ± 1.1 yrs, body mass 79.1 ± 20.3 kg, height 175.1 ± 7.4 cm) volunteered to participate in this study. All subjects participated in interscholastic sports (primarily American football, basketball and lacrosse) and were recruited from an after-school strength and conditioning program.

In this after-school program, participants received daily instruction on weightlifting movements, resistance training, plyometric exercises, and speed and agility from Certified Strength and Conditioning Specialists and weightlifting coaches. As per guidelines from USA Weightlifting (30), participants learned how to perform the front squat, Romanian deadlift and modified cleans, pulls, and presses with a wooden dowel before attempting more advanced exercises. Progression was based upon actual motor skill competence and technical proficiency. Proper exercise technique and lifting procedures which included instruction on how to safely "miss" a lift were reinforced during movement preparation activities and training sessions.

Training loads and exercises were progressed over time by members of the coaching staff as confidence and competence to perform advanced multi-joint exercises improved. If an exercise was performed incorrectly, the lifters performance was re-assessed by a member of the coaching staff and, if appropriate, the training load was reduced. Only lifters who demonstrated proper exercise technique during training sessions participated in 1 RM testing procedures in order to evaluate progress and determine appropriate training loads. On average, subjects in this investigation had 16.5 ± 1.1 months of experience performing various weightlifting movements including the power clean and snatch exercises.

Both the subjects and their parents were informed about the objectives and scope of this project and completed a health history and physical activity questionnaire. The exclusionary criteria used were a) subjects with a chronic pediatric disease, and b) subjects with an orthopedic limitation. All volunteers were accepted for participation.

Procedures

A USA Weightlifting Senior Level coach who trained several young athletes at the National School Age Weightlifting Championships evaluated performance on all 1 RM lifts. Certified Strength and Conditioning Specialists who had experience testing and training school-age youth assisted with testing protocols. All study procedures took place after-school (3:00 to 5:00 pm) during the Spring semester in a public high school strength and conditioning

facility using competition-caliber Olympic barbells and plates. All subjects were familiar with 1 RM testing procedures and were evaluated individually by qualified professionals. Prior to testing, all subjects participated in a 10-minute warm-up session which included dynamic movement activities for the ankles, hips, shoulders and wrists.

To perform the power clean exercise, subjects placed their hands on the barbell slightly wider than shoulder-width with their hips lower than the shoulders and the barbell about 3 cm in front of the lower leg region (shank) with their feet about hip-width apart. Subjects were reminded to “set the back” in the proper position with “chest up”, elbows rotated outwards and eyes looking forward. Subjects initiated the power clean by deliberately lifting the barbell off the floor with a forceful extension of their knees and hips while keeping their shoulders directly over the barbell. During this phase of the lift, the arms and chest were “tight” and the barbell remained close to the body.

As the barbell rose above the knees, each subject explosively transitioned into the second pulling phase by extending their hips, knees and ankles as if jumping into the air. When their lower body reached full extension, subjects forcefully shrugged their shoulders with both elbows fully extended. Subjects avoided the temptation to bend their elbows during this phase of the lift which is a common error in inexperienced lifters.

As the barbell continued to rise, subjects quickly flexed their elbows, hips, knees, and ankles to pull their bodies under the barbell to catch the weight in a quarter-squat position with feet about shoulder-width apart. By relaxing their grip during the catch phase of the lift, the subjects were able to receive the barbell across their shoulders with both elbows pointing forward. Subjects performed a quarter squat to the standing position once the barbell was located across the front of the clavicles and anterior deltoids. Although the power clean exercise consists of different phases, this movement requires the lifter to quickly and forcefully lift the barbell from the floor to the front of the shoulders in one continuous movement without interruption. Details of the power clean exercise have been previously described (14, 26).

In our investigation, the 1 RM was recorded as the maximum resistance that could be lifted using proper exercise technique for one repetition. Before attempting a 1 RM, subjects performed a progressive series of five submaximal sets of 1 to 2 reps with moderate to heavy loads (~50–90% of the estimated 1 RM). Weights prescribed for warm-up sets and testing were based upon a subject’s previous weightlifting experience or prior 1 RM test results which were noted on a “testing helper” data sheet. If a weight was lifted with proper form during a 1 RM trial, the subsequent 1 RM weight attempt was increased by approximately 2.5 to 7 kg and the subject attempted another 1 RM trial following ~ 3 minutes of rest. The increments in weight were dependent upon the effort required for the lift and became progressively smaller as the subject approached the 1 RM.

Appropriate progression of loading during 1 RM trials was determined by a senior level weightlifting coach who trained all subjects in this investigation. In the case of a failed 1 RM lift, subjects who attempted to maintain proper exercise technique without any major technical flaw in performance were permitted a second attempt at the same weight. Each subject’s 1 RM was determined within 3 to 5 trials. Qualified strength and conditioning professionals provided encouragement and reinforced the importance of proper exercise technique throughout all testing sessions with appropriate coaching cues. Three to 7 days after the first 1 RM trial, subjects returned to the center in the afternoon and performed the second 1 RM trial following the same testing protocol with the same instructors. Subjects were instructed to avoid heavy lifting for 48 hours prior to each testing session and observe proper nutrition practices including adequate hydration. Throughout the study period,

subjects were questioned by test administrators for the occurrence of an injury or complaints of muscle soreness.

Statistical Analyses

Statistical procedures were performed using SPSS version 17.0 for windows (Chicago, IL) and SAS version 9.1 (SAS Institute, Cary, NC). Descriptive statistics were calculated for all variables. The relative reliability of the data was determined using a two-way random effects model intraclass correlation coefficient (2, k) and Pearson correlation coefficient were calculated over the two test sessions. A repeated measures ANOVA was used to evaluate any potential difference between test days and significance was set at $p < 0.05$. Bland-Altman plots, linear regression analysis and typical error analyses (square root of mean square error) were also used to evaluate reliability. Accordingly, minimal differences (MD) needed to be considered real were calculated (typical error * 1.96 * square root of 2) in order to provide a measure of the clinical significance of the observed changes in power clean performance. Data are reported as means and standard deviations.

RESULTS

All subjects completed the study according to the aforementioned methodology. The 1 RM power clean was 70.6 ± 19.8 kg and 69.8 ± 19.8 kg on the first and second test session, respectively, with an ICC of 0.98 (95% CI = 0.96–0.99) and no significant difference in 1 RM power clean performance between trials ($p > 0.05$). The Pearson correlation coefficient demonstrated a strong relationship between 1 RM captured between test sessions ($r = 0.98$; $p < 0.0001$; figure 1). The Bland-Altman plot is presented in figure 2 and confirmed no systematic shift between 1 RM test sessions or association between difference and average with a calculated Pearson correlation of average vs between method difference of $r = -0.10$ ($= 0.978$). Linear regression (between the difference and the average) indicated an r -square of 0.00003, further confirming no association between difference and average measures. The degree of agreement between test 1 and test 2 was also evaluated by the mean difference and the 95% confidence limits. The average difference between the two testing trials was -0.751 kg, with a 95% confidence limit (-8.912 to 7.412) which indicate that the mean difference or error between test sessions was about 1% of the overall test measure in this population. The typical error to be expected with 1 RM power clean between test measures is 2.9 kg. The MD = 8.0 kg indicates that changes greater than 8.0 kg would be reflective of a real change in power performance with a re-test or post-training assessment. No injuries occurred throughout the study and no complaints of muscle soreness were reported.

DISCUSSION

To our knowledge, no other study has examined the reliability of 1 RM power clean testing in young lifters. Results of this investigation indicate that 1 RM power clean testing has a high degree of reliability in trained male adolescent athletes when standardized testing procedures are followed and qualified instruction is present. No untoward responses or injury occurred from 1 RM testing procedures. Despite previous concerns associated with 1 RM power testing in youth (2), our findings support the updated NSCA paper on youth resistance training and indicate that the maximal muscular power of healthy trained adolescences can be assessed with the 1 RM power clean (9). However, it must be underscored that subjects in this study were trained adolescent athletes who had experience performing weightlifting exercises and all procedures were administered by qualified professionals who were knowledgeable of pediatric resistance training guidelines and the pedagogical aspects of teaching weightlifting to school-age youth. The findings of this study may not be generalizable to untrained youth, or to cases in which test protocols are administered by inexperienced professionals.

Although data on 1 RM test-retest reliability in younger populations are limited, our data are consistent with previous reliability assessments performed on adult athletes. For example, McGuigan and Winchester reported an ICC of 0.98 for 1 RM power clean testing in American football players (21). Since the ICC is a measure of relative reliability that examines the consistency of individual scores (32), the observed ICC of 0.99 in the present investigation indicates that power clean testing is a highly reliable measure in trained adolescents. We previously reported ICCs of 0.93 to 0.98 for the 1 RM chest press and leg press tests in children (8–12 yrs) (12) and others reported high ICCs on a variety of upper and lower body 1 RM strength tests in adults (20). Of potential relevance, ICCs 0.90 have been found in children who performed sports-related tests of speed and agility and in adolescents who performed the drop vertical jump (1, 31). Researchers have used the 1 RM power clean to assess performance in adolescents and a recent survey of high school coaches revealed that “Olympic style lifts” and its variations were the most important exercises these coaches prescribed for their athletes (6, 8). Of note, data indicate that the risk of injury during the performance of weightlifting movements during training or competition is relatively low provided that qualified instruction is available and safety measures are in place (5, 10, 15).

The Bland-Altman plots presented in figure 2 show that the limits of agreement is small, suggesting that individual variability between 1 RM trials was negligible in our subject population. The Bland-Altman plot also confirmed that there was no systematic shift (i.e. learned effect) between 1 RM test sessions. The lack of association between difference and average also confirm that these methods do not provide systematic error. Moreover, linear regression (between the difference and the average) indicated an r-square of 0.00003 which represents cumulative and strong evidence that the 1RM test methods employed in the current population yield highly reliable outcome measures. From a practical perspective, highly reliable tests are able to detect small but significant changes in limited sample sizes and provide meaningful information to coaches and sport scientists regarding changes in physical performance (18). These findings indicate that the methods employed in the current study would be appropriate to assess the effects of interventions on weightlifting performance in adolescent athletes.

In our investigation, the difference between 1 RM testing trials was 0.8 kg (1.1%) and subjects completed the 1 RM tests with a mean of 3.1 and 3.4 trials, respectively, on day 1 and day 2. In addition, the typical error to be expected between 1 RM power clean trials was 2.9 kg and it appears that a change of at least 8.0 kg is needed to identify real changes in power clean performance over time. The high reproducibility of 1 RM power clean testing and acceptable measurement error in this study was likely due to a number of factors. Our population of adolescents had, on average, 16 months of experience performing a variety of weightlifting movements in a structured strength and conditioning program. Subjects progressed from basic movements (e.g. front squat) to more complex movements (e.g., power clean) as competence and confidence improved. Although training frequency varied throughout the year depending on sport participation and school vacations, most subjects participated in strength and conditioning activities at least twice per week and received constructive feedback on proper form and technique from weightlifting coaches. As previously noted by Kraemer et al (20), the process of increasing the weight to a true 1 RM can be enhanced by prior familiarization with the testing exercise as well as the expertise of investigators who evaluate the performance of each lift. Of interest, Blazeovich and Gill found significantly reduced reliability in an unfamiliar squat strength test in healthy adults who had at least one year of resistance training experience (4).

Despite the growing popularity of weightlifting by high school athletes and their coaches in the United States (8, 27), only limited normative data is available on the power clean

exercise for comparison. In the present investigation, subjects lifted ~ 70 kg on the 1 RM power clean whereas the reported 50th percentile for this lift in 14 to 15 year old high school American football players is 79 kg (17). Factors including training experience, testing procedures, quality of performance and body mass may have influenced the observed differences in performance. Also, subjects in our investigation participated in a variety of sports including American football, lacrosse, and basketball.

The results of current investigation indicate that 1 RM testing of the power clean exercise can be used to track progress, develop personalized programs and assess the effectiveness of youth strength and conditioning programs. In addition, 1 RM testing can provide motivation during yearly training cycles. However, proper administration of maximal strength and power testing procedures require qualified instruction and consistent feedback on technical movements and desired intensity progression. Although these tests can be used by pediatric researchers and youth strength and conditioning professionals to assess training-induced gains in strength and power, field tests such as the standing long jump or vertical jump may be more appropriate in physical education classes as a general index of muscular fitness in youth.

This study attempted to determine the reliability of the 1 RM power clean in trained adolescent athletes. Our substantive findings are consistent with similar tests measured in adults (21) (33) and supportive of previous investigations that examined 1 RM strength testing in children (12, 13). We found that technique-driven 1 RM power clean testing has a high degree of reproducibility in trained adolescents and can be safely evaluated in young athletes provided that standard testing procedures are followed. However, no conclusions can be made regarding the reliability of power clean testing in inexperienced young lifters. Future research might focus on establishing normative 1 RM power clean data for male and female high school athletes for comparative evaluations of maximal muscular power to age- and gender-matched peers.

PRACTICAL APPLICATIONS

Muscular power is a key component to athletic ability in many sports and there is growing interest in strength and conditioning in schools and youth sport training centers. The key finding from the present study is that the 1 RM power clean demonstrates excellent test-retest reliability and acceptable measurement error in trained adolescent male athletes. As it is paramount for youth coaches to assess performance with tests that are reliable, the 1 RM power clean can be added to protocols available to qualified professionals in order to monitor training-induced changes in strength and power and determine whether a real change in performance has occurred. It is also important for youth coaches to be able to reliably determine if gains in performance following a training program are real or an artifact of the measurement error associated with the test used to assess changes in performance. Our findings indicate that a difference in 1 RM power clean performance of less than 2.9 kg between tests is an expected variation for this exercise. In addition, it appears that a change of at least 8.0 kg is needed to identify a real change in 1 RM power clean performance as a result of strength and conditioning program in this young population.

Although administering 1 RM power clean tests according to the procedures outlined in this study may yield reliable data, unsupervised testing procedures or poorly performed exercises are not recommended under any circumstances because of the potential for injury and reduced validity of test measures (24). Substantive and consistent instruction from qualified professionals is an integral component for achieving highly reliable test measures in young athletes who need to develop the coordination and skill technique to perform these lifts correctly. Due to the high degree of reproducibility demonstrated in this study, the 1 RM

power clean can be considered a useful and meaningful test in high school strength and conditioning programs provided criteria-based testing guidelines are followed and practitioners have experience measuring parameters of weightlifting performance in young lifters.

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REFERENCES

1. Alricsson M, Harms-Ringdahl K, Werner S. Reliability of sports related functional tests with emphasis on speed and agility in young athletes. *Scand J Med Sci Sports*. 2001; 11:229–232. [PubMed: 11476428]
2. American Academy of Pediatrics. Strength training by children and adolescent. *Pediatrics*. 2008; 121:835–840. [PubMed: 18381549]
3. Behm DG, Faigenbaum AD, Falk B, Klentrou P. Canadian Society for Exercise Physiology position paper: resistance training in children and adolescents. *Appl Physiol Nutr Metab*. 2008; 33:547–561. [PubMed: 18461111]
4. Blazeovich A, Gill N. Reliability of unfamiliar, multijoint, uni- and bilateral strength tests: effects of load and laterality. *Journal of Strength and Conditioning Research*. 2006; 20:226–230. [PubMed: 16503686]
5. Byrd R, Pierce K, Rielly L, Brady J. Young weightlifters' performance across time. *Sports Biomechanics*. 2003; 2:133–140. [PubMed: 14658250]
6. Channell BT, Barfield JP. Effect of Olympic and traditional resistance training on vertical jump improvement in high school boys. *J Strength Cond Res*. 2008; 22:1522–1527. [PubMed: 18714236]
7. Cronin J, Sleivert G. Challenges in understanding the influence of maximal power training on improving athletic performance. *Sports Medicine*. 2005; 35:213–234. [PubMed: 15730337]
8. Duehring MD, Feldmann CR, Ebben WP. Strength and conditioning practices of United States high school strength and conditioning coaches. *Journal of Strength and Conditioning Research*. 2009; 23:2188–2193. [PubMed: 19826308]
9. Faigenbaum A, Kraemer W, Blimkie C, Jeffreys I, Micheli L, Nitka M, Rowland T. Youth resistance training: Updated position statement paper from the National Strength and Conditioning Association. *Journal of Strength and Conditioning Research*. 2009; 23:S60–S79. [PubMed: 19620931]
10. Faigenbaum A, Myer G. Resistance training among young athletes: Safety, efficacy and injury prevention effects. *British Journal of Sports Medicine*. 2010; 44:56–63. [PubMed: 19945973]
11. Faigenbaum, A.; Westcott, W. *Youth Strength Training*. Champaign, IL: Human Kinetics; 2009.
12. Faigenbaum A, Westcott W, Long C, Loud R, Delmonico M, Micheli L. Relationship between repetitions and selected percentages of the one repetition maximum in healthy children. *Pediatric Physical Therapy*. 1998; 10:110–113.
13. Faigenbaum AD, Milliken LA, Westcott WL. Maximal strength testing in healthy children. *J Strength Cond Res*. 2003; 17:162–166. [PubMed: 12580672]
14. Garhammer J. A review of power output studies of Olympic and powerlifting: methodology, performance prediction, and evaluation tests. *Journal of Strength and Conditioning Research*. 1993; 7:76–89.
15. Hamill B. Relative safety of weight lifting and weight training. *Journal of Strength and Conditioning Research*. 1994; 8:53–57.
16. Harman, E.; Garhammer, J. Administration, scoring and interpretation of selected tests. In: Baechle, T.; Earle, R., editors. *Essentials of Strength and Conditioning*. Champaign, IL: Human Kinetics; 2008. p. 249–292.
17. Hoffman, J. *Norms for Fitness, Performance and Health*. Champaign, IL: Human Kinetics; 2006.

18. Hopkins WG. Reliability of power in physical performance tests. *Sports Medicine*. 2001; 31:211–234. [PubMed: 11286357]
19. Hori N, Newton H, Nosaka K, Stone M. Weightlifting exercises enhance athletic performance that requires high-load speed strength. *Strength and Conditioning*. 2005; 27:50–55.
20. Kraemer, W.; Ratamess, N.; Fry, A.; French, D. Strength training: Development and evaluation of methodology. In: Maud, P.; Foster, C., editors. *Physiological Assessment of Human Fitness*. Champaign, IL: Human Kinetics; 2006. p. 119-150.
21. McGuigan M, Winchester JB. The relationship between isometric and dynamic strength in collegiate football players. *Journal of Sports Science and Medicine*. 2008; 7:101–105.
22. Milliken LA, Faigenbaum A, Loud R, Westcott W. Correlates of upper and lower body muscular strength in children. *Journal of Strength and Conditioning Research*. 2008; 22:1339–1346. [PubMed: 18545169]
23. Mountjoy M, Armstrong N, Bizzini L, Blimkie C, Evans J, Gerrard D, Hangen J, Knoll K, Micheli L, Sanganis P, Van Mechelen W. IOC consensus statement: Training the elite young athlete. *Clinical Journal of Sports Medicine*. 2008; 18:122–123.
24. Myer G, Quatman C, Khoury J, Wall E, Hewett T. Youth vs. adult "weightlifting" injuries presented to United States Emergency Rooms: Accidental vs. non-accidental injury mechanisms. *Journal of Strength and Conditioning Research*. 2009; 23:2054–2060. [PubMed: 19855330]
25. Myer G, Wall E. Resistance training in the young athlete. *Operative Techniques in Sports Medicine*. 2006; 14:218–230.
26. Newton, H. *Explosive Lifting for Sports*. Champaign, IL: Human Kinetics; 2002.
27. Pierce K, Bryd R, Stone M. Youth weightlifting - Is it safe? *Weightlifting USA*. 1999; 17:5.
28. Safrit, M. *Complete Guide to Youth Fitness Testing*. Champaign, IL: Human Kinetics; 1995.
29. United States Department of Health and Human Services. 2008 Physical Activity Guidelines for Americans. 2008. www.health.gov/paguidelines
30. USA Weightlifting. *USA Weightlifting Club Coach Manual*. Colorado Springs, CO:
31. Walsh M, Ford K, Bangen K, Myer G, Hewett T. The validation of a portable force plate for measuring force-time data during jumping and landing tasks. *Journal of Strength and Conditioning Research*. 2006; 20:730–734. [PubMed: 17194240]
32. Weir J. Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. *Journal of Strength and Conditioning Research*. 2005; 19:231–240. [PubMed: 15705040]
33. Weiss L, Moore C, Schilling B, Ermert R, Fry A, Chiu L. Reliability and precision of multiple expressions of hand power clean bar velocity. *Journal of Strength and Conditioning Research*. 2005; 19:e36.

Figure 1. Scatterplot depicting the relationship between 1 RM trials. The 95% confidence interval about the slope coefficient was (0.91 to 1.1)

Figure 2.

Bland-Altman plot of 1 RM power clean performance. The solid line represents the mean difference between RM trials. Dotted line represents the 95% confidence limits for the measured difference.