COMPARISON OF CONCENTRIC AND ECCENTRIC BENCH PRESS REPETITIONS TO FAILURE

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ABSTRACT

Kelly, SB, Brown, LE, Hooker, SP, Swan, PD, Buman, MP, Alvar, BA, and Black, LE. Comparison of concentric and eccentric bench press repetitions to failure. J Strength Cond Res 29(4): 1027–1032, 2015—Eccentric muscle actions (ECC) are characterized by muscle lengthening, despite actin-myosin crossbridge formation. Muscles acting eccentrically are capable of producing higher levels of force compared with muscles acting concentrically. The purpose of this study was to determine whether ECC bench press yields greater strength than concentric (CON) as determined by 1 repetition maximum (1RM). Additionally, a comparison was made examining differences in the number of repetitions to failure at different relative intensities of 1RM. Thirty healthy men (age = 24.63 ± 5.68 years) were tested for 1RM in CON and ECC bench press and the number of repetitions completed at 60, 70, 80, and 90% 1RM. For CON repetitions, the weight was mechanically lowered to the chest, and the participant pressed it up until the elbows were fully extended. The ECC bench press consisted of lowering a barbell from a fully extended elbow position to the chest in a continuous controlled manner for 3 seconds as determined by electronic metronome. Paired t-tests showed that ECC 1RM (115.99 ± 31.08 kg) was significantly (p ≤ 0.05) greater than CON 1RM (93.56 ± 26.56 kg), and the number of repetitions completed at 90% 1RM was significantly (p < 0.05) greater in ECC (7.67 ± 3.24) as compared with CON (4.57 ± 2.21). There were no significant differences in number of completed repetitions during CON and ECC bench press at 60, 70, and 80% 1RM. These data indicate that ECC actions yield increased force capabilities (~120%) as compared with CON in the bench press and may be less prone to fatigue, especially at higher intensities. These differences suggest a need to develop unique strategies for training eccentrically.

KEY WORDS resistance, strength, fatigue

INTRODUCTION

Eccentric (ECC) muscle actions occur when the force exerted by working muscle is less than that of an external resistance. This is characterized by muscle lengthening, despite actin-myosin crossbridge formation. Thus, the separation of myosin from actin is mechanical rather than chemical (11). This is in contrast to concentric (CON) muscle actions, during which the muscle shortens as actin filaments are pulled over myosin filaments. During CON actions, crossbridges are separated through the cleaving of an ATP molecule. The chemical reaction of a CON muscle action results in less muscular damage than ECC muscle action.

ECC actions, when emphasized during resistance training, may elicit greater strength adaptation (4,18,23) muscular hypertrophy (13,14,23), and acute increases in subsequent CON force capabilities (8,21) and favorable acute inflammatory response (13) compared with traditional ECC/CON actions and CON muscle actions alone. Studies also suggest that muscles are less prone to fatigue when acting eccentrically (6,10). Based on the emergence of research supporting the utilization of ECC muscle actions for a variety of outcomes, programs that emphasize ECC actions through resistance training methods have become increasingly popular.

As evidence of the effectiveness of ECC training emerges, it is important to ensure that basic scientific principles of traditional training are applied. A training program using a prescribed number of sets and repetitions with a specified intensity remains the most effective way to maximize the benefits of resistance training and improve the likelihood of desired adaptations (12,20). This is generally done by measuring or predicting an individual’s 1 repetition maximum (1RM) in a particular exercise and using that value to determine submaximal intensities to be used during training.
A number of tables have appeared in the literature (1,7,19), which may be useful for estimating 1RM based on the number of repetitions an individual is able to complete with a given weight. Alternately, the tables can be used for estimating the number of repetitions an individual should be able to achieve given their 1RM and the percentage of that 1RM they are lifting. These tables are designed through prediction equations extrapolating norms from data, which have been collected in research studies. Tables suggesting weights and repetitions per different percentages of 1RM provide information useful in program design, minimization of injury potential, and creating a time-efficient reference tool for use in the manipulation of training variables such as volume and intensity. However, each of these tables is designed for use with traditional muscle actions, which consists of an ECC action immediately followed by a CON action. In these ECC/CON movements, the limiting factor in whether or not the repetition is successful is nearly always the CON action. This is attributed to the fact that ECC force capabilities are 120–200% of CON force capabilities (2,9,10,15,16). It is unclear how increased force capability and seemingly greater resistance to fatigue (6,10) translates to the number of repetitions, which can be completed eccentrically, as compared with existing norms in the research, which describe ECC/CON repetitions. This study seeks to address the practical question of how the physiological differences between CON and ECC muscle actions relate to performance in a common exercise.

No known literature exists, which describes a prediction equation for ECC-only muscle actions, and as previous research suggests, muscles performing ECC actions may respond differently than muscles acting concentrically (4,10,17). It remains to be examined whether CON and ECC muscle actions react similarly in terms of repetitions to failure at the same relative intensity. Therefore, it is important to understand the unique characteristics of ECC muscle actions, including force capabilities, fatigue patterns, neural patterns, and training adaptations to ECC-emphasized exercise. The purpose of this study was to determine differences between CON 1RM and ECC 1RM values on the bench press and to examine the number of repetitions completed at each percentage of 1RM between CON and ECC muscle actions. These comparisons offer a practical examination of how CON and ECC muscle actions may require unique training strategies for maximal health and performance adaptation.

**Methods**

**Experimental Approach to the Problem**

One repetition maximum loads were measured in the bench press exercise for both CON and ECC actions. A mechanical hoist allowed for the load to be passively lowered to the chest (CON) or raised to the starting position (ECC). One repetition maximum values were compared between muscle actions. Loads of 60, 70, 80, and 90% mode-specific 1RM were then lifted to volitional failure. The number of repetitions completed at each intensity was compared between muscle actions. This design allows for comparison of 1RM data, as well as the mode-specific patterns of fatigue as expressed in repetitions completed.

**Subjects**

Thirty men (age = 24.63 ± 5.6 years, age range 19–40 years; height = 178.61 ± 6.58 cm; mass = 83.72 ± 11.43 kg) with a self-report of at least 1 year of resistance training experience volunteered to participate in this study. Resistance training experience was defined as having performed the bench press exercise a minimum average of once per week during the past year. The specific training goals of the participants’ previous programs (i.e., hypertrophy, strength, and muscular endurance) were not considered, nor were the typical volume, intensity, rest, or frequency (beyond the minimum once weekly criteria). Exclusion criteria included orthopedic injuries and pain in the upper extremities within the past year, current hypertension (defined as resting blood pressure higher than 160/90 mm Hg), and cardiovascular risk factors as reported as one or more items selected on the Physical Activity Readiness Questionnaire. Before participation, all subjects read and signed an informed consent approved by the university Institutional Review Board.

**Procedures**

This study consisted of 6 testing sessions per participant over a 4-week period at approximately the same time of day for each individual. Study participants were asked to maintain a consistent routine before each test session in terms of diet, hydration, and rest. Participants were measured for anthropometric measures of height, and mass. After anthropometric measures in the initial session, and before lifting in each subsequent session, participants performed a general warm-up by pedaling a Monark cycle ergometer (Monark, Varberg, Sweden) for 5 minutes at 90 rpm. During each session, the cycle ergometer warm-up was followed by a specific bench press warm-up consisting of 10, 5, and 3 repetitions at self-selected, but increasing, loads for a traditional bench press exercise (characterized as the MCC [lowering] action immediately followed by the CON action [raising]). Repetitions were completed in succession without rest with 1-minute rest between sets.

The initial 2 sessions included testing 1RM in either CON or ECC bench press in random order as determined by flip of a coin. Participants were allowed to practice each method of lift with the unloaded barbell to become accustomed to the timing of the lifts and familiar with the procedures. The CON bench press was performed with the participant supine on a bench and pushing the barbell from a resting position on the chest to complete extension of the elbows. The weight was passively lowered to the chest before each repetition through mechanical hoist (2000 lb Minsize Electric Rope Hoist; Northern Tool and Equipment, Burnsville, MN) mounted on a 2000-lb capacity gantry crane (Figure 1). A failed CON repetition was defined as
the participant being unable to completely extend the elbows to complete the movement. The ECC bench press consisted of lowering a barbell with weight from a fully extended elbow position to the chest in a continuous, smooth, controlled manner for 3 seconds as determined by a Korg MA-30 Ultra Compact digital metronome (Korg, Melville, NY). The barbell and weight were then returned to the starting position through the mechanical hoist. A failed ECC repetition was defined as the participant being unable to control the velocity of the descent of the bar at any time or allowing the barbell to touch the chest before the full 3-second count expired. This protocol is similar to those reported in previous studies (5,16).

Participants were given 2- to 5-minute rest between 1RM attempts as per National Strength and Conditioning Association guidelines (1). Two to six attempts were performed to determine each participant's 1RM load. The greatest weight attained in each lift was used as the 1RM.

The third through sixth sessions included the warm-up protocols followed by the maximal repetition testing. Each of the 4 testing days was used to determine the number of repetitions the participant was able to complete for 1 ECC and 1 CON percentage (60, 70, 80, and 90%) of each respective 1RM. The order of exercise and percentage of 1RM was randomized without replacement. Percentage values of either ECC or CON were written on strips of paper the participants blindly picked when they arrived for testing. Participants were aware of the percentage and amount of weight they were using. Once a specific percentage/test combination was performed, it was removed from the choice selections for the subsequent visits until each participant completed each percentage for each CON and ECC tests. All sets were performed to volitional failure, defined as the first failed repetition in the set. Ten minutes of rest were given between testing sets at all percentages. The number of repetitions completed at each percentage of 1RM was recorded.

To ensure the safety of all participants, trained spotters were used during all warm-up and testing sets on the bench press. Additionally, at the commencement of each testing session, the mechanical hoist was lowered to the appropriate height, with the barbell lightly touching the participant's chest. The cable was marked with a small piece of tape, indicating where the operator should stop the hoist. This ensured the cable would prevent the bar from falling onto the participant in the event of a failed lift. Gym chalk was available for participants who wished to use it but was not mandatory.

**Statistical Analyses**

Data were analyzed using SPSS software (version 19.0; SPSS, Inc., Chicago, IL, USA). Data were examined for normality using test statistics for skewness and kurtosis as well as visual inspection of the data. Data, which were not normally distributed, were transformed using a natural logarithmic transformation for analysis and back-transformed for presentation. Intraclass correlation coefficients were performed for 1RM, and repetitions to failure. Paired t-tests were used to determine differences between CON and ECC 1RM. Paired t-tests were also used to determine differences in number of repetitions completed at each 1RM percentage (60, 70, 80, and 90%) between CON and ECC.

**RESULTS**

**Concentric 1 Repetition Maximum vs. Eccentric 1 Repetition Maximum**

Intraclass correlation coefficients for 1RM was 0.964 (p < 0.01). A paired t-test showed significantly (p ≤ 0.05) greater 1RM in ECC (115.99 ± 31.08 kg) when compared with CON (93.56 ± 26.56 kg).
actions. These data indicate ECC strength was approximately 124% of that of CON strength (Table 1).

Repetitions Completed for CON vs. ECC
Intraclass correlation coefficients for repetitions to failure was significant \( p < 0.05 \) but low (0.478). Paired \( t \)-tests revealed significantly \( p < 0.05 \) greater number of repetitions completed at 90% 1RM for ECC = 7.67 ± 3.24 when compared with CON = 4.57 ± 2.21 muscle actions. There were no significant differences between the number of repetitions completed concentrically and eccentrically at any other intensity (Figure 2).

**DISCUSSION**

This study examined differences between CON and ECC bench press in terms of 1RM and the number of repetitions completed at various percentages (60, 70, 80, and 90%) of mode-specific 1RM. Overall, the findings were (a) ECC 1RM was significantly \( p < 0.05 \) greater than CON 1RM, (b) a significant \( p < 0.05 \) difference between the number of repetitions completed at 90% of mode-specific 1RM, and (c) no differences between the number of repetitions completed at any of the other mode-specific 1RM relative intensities.

Based on previous research (2,9,10,15,16), it was hypothesized that ECC 1RM would be approximately 120% of CON 1RM. These data support this as ECC 1RM was approximately 124% of CON 1RM, a statistically significant \( p < 0.05 \) difference. Our confirmatory results establish the present research design (5), particularly the protocol for testing ECC repetitions, as a valid measure of ECC strength.

No known studies compare the number of repetitions participants can complete in the bench press exercise with an equated relative load concentrically and eccentrically. Studies comparing fatigue patterns between CON and ECC muscle actions have been performed using isokinetic dynamometry (3,17,18,22), but testing the number of repetitions completed before volitional failure, as characterized by the inability to complete a repetition, is difficult and has not been previously done to the best of our knowledge. However, previous research has focused on decreases in muscular force as a result of repeated bouts of CON and ECC exercise as measured by isokinetic dynamometry, but as previously stated, not on how many repetitions actually completed. Tesch et al. (22) showed no force decreases as a result of 3 bouts of 32 maximum voluntary ECC repetitions, as compared with the same number of CON repetitions, which resulted in 34–47% decreases in force. Binder-Macleod and Lee (3) showed very different patterns of fatigue between CON and ECC exercise over the course of 180 invoked knee extensions, with CON resulting in a very sharp decline in force over the first 40 repetitions and no further force decreases after the 80th repetition, and ECC showing a linear decrease from the 15th to the 180th repetition. Muscle actions were invoked at 20% of maximum voluntary isometric force. Force outputs were statistically greater in ECC actions than CON actions for both of these studies.

Taken together, these studies indicate that not only can the muscle produce more force eccentrically but also it can maintain force production over a longer period of time under ECC conditions as compared with CON. What is unclear, however, is whether this apparent heightened resistance to fatigue results in a greater number of ECC repetitions that can be completed in a free weight exercise when compared with CON repetitions, particularly under the same relative intensities. A key difference between isokinetic dynamometry and free weights revolves around the possibility of a failed repetition: a participant may exhibit fluctuations of force throughout a set of isokinetic exercise but will still be able to complete the prescribed number. Conversely, if there is
a sufficient decrease in force during a set of free weight exercise, the repetition will be unsuccessful and the set terminated.

This study indicates that with an equated load (i.e., equal percentage of mode-specific 1RM), there is a significant difference between the number of repetitions that can be completed concentrically and eccentrically at 90% 1RM. There were no differences in repetitions to failure at any other relative intensity of 1RM. This seems to support existing research, which suggests differences between CON and ECC actions in terms of fatigue rate. Studies by Enoka (10), Tesch et al. (22), and Binder-Macleod and Lee (3) all indicated that muscles acting eccentrically are slower to fatigue. What is unclear throughout the research, however, is how this slower fatigue rate, which was observed largely through isokinetic testing and EMG data translates to actual repetitions of an exercise an individual is able to perform. The issue remains unclear as noted by the fatigue curves displayed in this study indicating similar rates of fatigue between CON and ECC muscle actions at the tested relative intensities.

This is the first known study to directly measure ECC 1RM and test participants at various intensities of that 1RM using free weights. This allows for a truly equated testing load, which has not been present in studies that estimated ECC 1RM (15) or used isokinetic dynamometry (3,22). With an equated load, differences between CON and ECC performance capabilities are minimized. Research is still unclear regarding an accepted methodology for the duration of ECC repetitions, with previous studies ranging from 2 seconds (15) to 4 seconds (23). Such a wide range of time under tension during a repetition could lead to major differences in the number of repetitions completed. We felt 3 seconds (16) was an appropriate duration for ECC repetitions, but acknowledge further research is required to determine the optimal amount of time under tension during ECC exercise. Our data show that under free weight conditions and with an equated load, there remains a different failure rate between CON and ECC actions. The fact that there was a significant difference at 90% 1RM, followed by decreasing differences at 80, 70, and 60% seems to be similar to the pattern of fatigue reported by Binder-Macleod and Lee (3).

Because of the nature of ECC muscle actions, particularly in the bench press exercise, it can be difficult to distinguish between a successful and an unsuccessful repetition. Because the weight is lowered toward the chest due to gravity, the participant must control the descent throughout the range of motion for a repetition to be deemed successful. Because of the difficulty determining the success of an ECC repetition, there are very few known studies (5) examining ECC 1RM or ECC repetitions to failure using free weights. Hollander et al. (16) tested ECC 1RM in a number of exercises, including bench press, using a similar protocol to ours using a weight stack. A failed repetition is fairly easy to distinguish whether the muscle is acting concentrically. In the standard bench press exercise, if a failure occurs during the CON phase, the bar will stop ascending and will eventually descend back toward the chest. Another factor, which complicates ECC testing with free weights, is the necessity of returning the weight to the starting position without requiring a CON muscle action. This can only be done with 1 or more spotters or mechanical assistance (16), as was used in this study. This can prove challenging for researchers.

With these issues considered, the research team set forth the guidelines for determining a “successful” ECC repetition. The subject was to lower the bar toward the chest in a smooth continuous motion over a 3-second duration in cadence with a digital metronome. The 3-second ECC phase was selected as an average between previously reported methods, which ranged from 2 seconds (15) to 4 seconds (23). Hollander et al. (16) also tested ECC 1RM using a 3-second repetition set to a metronome. In our study, the same tester was responsible for determining the success of every repetition for every participant to maximize intra-rater reliability. Thus, the use of a single trained tester and digital metronome minimized error in determining the success of a repetition.

Practical Applications
Eccentric muscle actions are a part of daily living and a large component of many sport and occupational demands. Because they are often performed sequentially with less forceful CON actions, ECC muscle actions are often underloaded and, therefore, undertrained. Training with an emphasis on ECC actions yields greater strength and hypertrophic gains than in programs in which ECC actions are not emphasized. With greater training potential for strength increases, hypertrophic gains, and the frequency with which ECC muscle actions are required in daily life and sport, it seems intuitive that a comprehensive training program includes exercises, which emphasize ECC muscle actions. More research is required to establish proper training protocols regarding frequency, intensity, and rest required for ECC actions due to differences in force capabilities, fatigue patterns, and potential muscular damage. Our findings offer further evidence that muscles acting eccentrically produce greater force than those acting concentrically. Our data also indicate differences in the patterns of fatigue between muscle action. Strength and conditioning professionals should attempt to account for these potential differences as they design resistance training programs.

References


