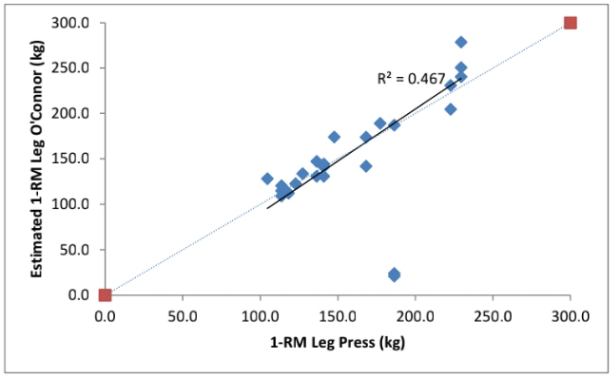



Figure 3. Correlation of actual 1RM and estimated 1RM using O'Connor equation for leg press

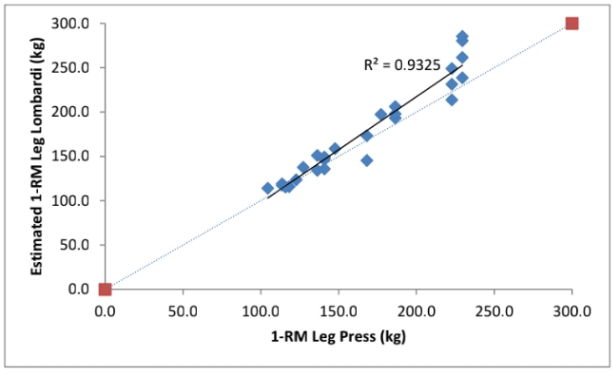



Figure 4. Correlation of actual 1RM and estimated 1RM using Lombardi equation for leg press

**Discussion**

The present study determined predictive equations of chest press 1RM exhibited a non-significant over estimation by an average of 1.9 kg or 2.5% for O'Connor and 0.3 kg or 0.3% for Lombardi when compared to actual 1RM. However it does differ from Lesuer's findings of the O'Connor and Lombardi equations to underestimate bench press 1RM by an average of 8.2 lbs or 6% and 4.3 lbs or 3%, respectively. Mayhew observed the O'Connor equation to underestimate bench press 1RM by an average of 2.0 kg or 2.3%, but the Lombardi equation overestimate bench press 1RM by an average of 0.3 kg or 0.3%. Furthermore, the present study determined predictive equations of leg press 1RM exhibited a significant over estimation by an

**Discussion**

The present study determined predictive equations of chest press 1RM exhibited a non-significant over estimation by an average of 1.9 kg or 2.5% for O'Connor and 0.3 kg or 0.3% for Lombardi when compared to actual 1RM. However it does differ from Lesuer's findings of the O'Connor and Lombardi equations to underestimate bench press 1RM by an average of 8.2 lbs or 6% and 4.3 lbs or 3%, respectively. Mayhew observed the O'Connor equation to underestimate bench press 1RM by an average of 2.0 kg or 2.3%, but the Lombardi equation overestimate bench press 1RM by an average of 0.3 kg or 0.3%. Furthermore, the present study determined predictive equations of leg press 1RM exhibited a significant over estimation by an average of 14.6 kg or 8.8% for O'Connor and 10.4 kg or 6.3% for Lombardi when compared to actual 1RM. This is much greater than McNair's findings of the O'Connor and Lombardi equations both underestimated leg press 1RM by an average of 4.4 kg or 6.6% and 3.4 kg or 5.1%, respectively (9).

The present study determined the estimated chest press 1RM from the O'Connor equation to have a validity coefficient of R = 0.95. This is lower than previous literature from Lesuer, who observed a correlation of R = 0.99, and Mayhew who observed a correlation of R = 0.96. Estimated chest press 1RM from the Lombardi equation reported a validity coefficient of R = 0.99. This is greater than previous literature from Mayhew, who observed a correlation of R = 0.96, but identical with Lesuer's findings. Furthermore, the present study determined the estimated leg press 1RM from the O'Connor equation to have a validity coefficient of R = 0.92. This is lower than previous literature form McNair, who observed a correlation of R= 0.97.

Estimated leg press 1RM from the Lombardi equation reported a validity coefficient of R = 0.97. This is lower than previous literature form McNair, who observed a correlation of R= 0.98.

Potential explanations for any differences in outcomes can be linked to variation in the number of repetitions performed during the RTF test. This could be influenced by an erroneously low measurement of 1RM due to premature termination of test. Subsequently an erroneously lower 80% of 1RM for the RTF test. A subject in this situation will be able to perform a greater amount of repetitions if the submaximal weight is a smaller percent of 1RM. A quantified decrease in load and subsequently increase in repetition is known to make all predictive equations less

Relationship of Linear and Nonlinear Equations to Estimate One Repetition Maximum

**Introduction**

Muscular strength is the maximum force generated by a muscle or group of muscles (1). The gold standard for muscular strength assessment is to measure one repetition maximum (1RM) (3). It is defined as the greatest resistance moved through the full range of motion in a controlled manner while maintaining good posture (12). Testing for 1RM can be performed with free weights or resistance machines for a specified exercise. A resistance training program can use 1RM as a resourceful measurement to establish baseline strength, monitor progress and control exercise intensity (%1RM). However, performing a 1RM test is highly strenuous on the muscles, bones, and connective tissue which could expose risk to those unaccustomed or untrained without the proper lifting technique (7).

An alternative approach to measure an individual's 1RM is by submaximal testing. Submaximal tests have an individual select a perceived weight less 1RM to be lifted as many repetitions as possible, known as a repetition to fatigue (RTF) test. Predictive equations use the submaximal weight lifted and the number of repetitions performed to estimate the individual's 1RM. There are numerous predictive equations have been developed to estimate 1RM. Predictive equations can be linear such as the one proposed by O'Connor and some equations are nonlinear such as the one proposed by Lombardi.

Previous literature on estimated bench press 1RM observed a significant correlation for the O'Connor (R = 0.99) and Lombardi (R = 0.99) equations between actual 1RM, both equations reported underestimate values (4). Another study on estimated bench press 1RM observed a

significant correlation for the O'Connor (R =0.96) and Lombardi (R = 0.96) equations between actual 1RM. The O'Connor equation underestimated bench press 1RM, but the Lombardi equation overestimated bench press 1RM (8). Previous literature on estimated leg press 1RM observed significant correlation for the O'Connor (R =0.97) and Lombardi (R = 0.98) equations between actual 1RM. The O'Connor and Lombardi equations both reported to underestimate leg press (9). All the studies mentioned above extrapolated estimated 1RM results from the RTF test completed in ≤ 10 repetitions.

The accuracy of predictive equations can vary according to the number of repetitions performed

exertion. This will reduce the likelihood of injury, especially those unaccustomed or untrained without the proper lifting technique (7). Perhaps a more popular practical implication is the difference of time completing a 1RM test and RTF test to predict 1RM. Anecdotally, 98 participants completed a 1RM bench press in 6 hours with 3 examiners. This same group completed a RTF test to predict 1RM in 2.5 hours with only one examiner (2). Therefore estimating 1RM with predictive equations is the more practical consideration when testing large numbers of participants.

**Reference Page**

1. Åstrand, P, Rodahl, K. Textbook of work physiology. (NY) McGraw-Hill Book Company; 1986
2. Chapman PP., Whitehead JR, Binkert, RH. The 225-lb reps-to-fatigue test as a submaximal estimate of 1-RM bench press performance in college football players. *Journal of Strength and Conditioning Research*. 1998; 12(4), 258- 261.

significant correlation for the O'Connor (R =0.96) and Lombardi (R = 0.96) equations between actual 1RM. The O'Connor equation underestimated bench press 1RM, but the Lombardi equation overestimated bench press 1RM (8). Previous literature on estimated leg press 1RM observed significant correlation for the O'Connor (R =0.97) and Lombardi (R = 0.98) equations between actual 1RM. The O'Connor and Lombardi equations both reported to underestimate leg press (9). All the studies mentioned above extrapolated estimated 1RM results from the RTF test completed in ≤ 10 repetitions.

The accuracy of predictive equations can vary according to the number of repetitions performed in the submaximal test. Other factors such as age, gender, specific exercise performed, training status and recovery periods can all influence the number of repetitions performed (11). The purpose of this present study is to compare the estimated 1RM values of the linear O'Connor equation and nonlinear Lombardi equation for both chest press and leg press. Additionally, the correlation between estimated and actual 1RM using both predictive equation will be investigated for each exercise.

**Methods**

A total of 30 subjects (16 males and 14 females) with a mean height of 170.6 ± 8.1 cm and mean weight of 71.3 ± 13.9 kg participated in this study. The study consisted of 1 repetition maximum (1RM) test and repetition to fatigue testing (RTF) which was then converted into an estimated 1RM using predictive equations. The tests were performed on the Cybex chest press machine and Cybex leg press machine. For leg press, the seat was adjusted so the starting angle is about 90 degrees at the knee. Feet were positioned shoulder width apart with toe pointed slightly outward. Muscular force was exerted on the foot plate until legs were fully extended. For chest

press, the seat bottom and back were adjusted so handles were at mid-chest. Hands were in a position to allow them to finish in front of the shoulders. Muscular force was exerted until the arms were fully extended.

*One Repetition Maximum Testing (1RM)*

1RM testing included a warm up set(s) at a self-selected weight specific for each exercise. The test was completed within four trials with 3 to 5 minutes rest between each trial. Weight lifted for trial one started approximately at 50% to 70% of subject's perceived capacity and weight progression increased by 2.5 to 25 kg (5.5 to 44.0 pounds). Each trial was performed at the same

Estimated leg press 1RM from the Lombardi equation reported a validity coefficient of R = 0.97. This is lower than previous literature form McNair, who observed a correlation of R= 0.98.

Potential explanations for any differences in outcomes can be linked to variation in the number of repetitions performed during the RTF test. This could be influenced by an erroneously low measurement of 1RM due to premature termination of test. Subsequently an erroneously lower 80% of 1RM for the RTF test. A subject in this situation will be able to perform a greater amount of repetitions if the submaximal weight is a smaller percent of 1RM. A quantified decrease in load and subsequently increase in repetition is known to make all predictive equations less accurate (11). Inadequate rest between trials can be a potential reason for early onset of fatigue, although a 1-minute rest interval has been indicated to be sufficient enough for repeated maximal effort squats (6).

To summarize these findings, the nonlinear Lombardi equation revealed to be more accurate than the linear O'Connor equation. Lombardi equation revealed a stronger correlation at estimating 1RM for chest press and leg press from actual 1RM. In addition, it deviated less from the mean values of 1RM in both exercises. Although estimated 1RM for leg press was significantly higher in both predictive equations than actual 1RM, Lombardi displayed to be more statistical relevant than the O'Connor equation because of the greater coefficient correlation. Chest press was observed to have a less statistical difference than leg press when linear and nonlinear predictive equations were compared. However, both linear and nonlinear predictive equations in this study proved to be an acceptable way to estimate 1RM. This has practical implications because submaximal strength testing reduces the amount of stress placed on subject during maximal

exertion. This will reduce the likelihood of injury, especially those unaccustomed or untrained without the proper lifting technique (7). Perhaps a more popular practical implication is the difference of time completing a 1RM test and RTF test to predict 1RM. Anecdotally, 98 participants completed a 1RM bench press in 6 hours with 3 examiners. This same group completed a RTF test to predict 1RM in 2.5 hours with only one examiner (2). Therefore estimating 1RM with predictive equations is the more practical consideration when testing large numbers of participants.

press, the seat bottom and back were adjusted so handles were at mid-chest. Hands were in a position to allow them to finish in front of the shoulders. Muscular force was exerted until the arms were fully extended.

*One Repetition Maximum Testing (1RM)*

1RM testing included a warm up set(s) at a self-selected weight specific for each exercise. The test was completed within four trials with 3 to 5 minutes rest between each trial. Weight lifted for trial one started approximately at 50% to 70% of subject's perceived capacity and weight progression increased by 2.5 to 25 kg (5.5 to 44.0 pounds). Each trial was performed at the same velocity and range of motion (ROM) for consistency. Test was finished when the subject can no longer complete a full repetition and final weight successfully lifted was recorded as 1RM (12).

*Repetition to Failure Testing (RTF)*

RTF testing included a warm up set(s) at a self-selected weight specific for each exercise. Submaximal weight for the RTF test was 80% of the subject's measured 1RM. The subject performed as many repetitions as possible with proper form until fatigue.

*Predictive Equations*

The number of repetitions and submaximal weight lifted are entered into two predictive equations to estimate 1RM for each exercise. The O'Connor equation assumed a linear relationship between repetitions and weight lifted, 1RM = weight lifted x (1 + 0.025 x repetitions). (10). The Lombardi equation assumed a nonlinear or curvilinear relation between repetitions and weight lifted, 1RM = weight lifted x repetitions$^{0.1}$ (5).

*Statistical Analysis*

Paired t-test were used to determine the mean differences between estimated 1RM from the predictive equations and measured 1RM. Repeated measures analysis of variance (ANOVA) was used to conduct regression analysis. A validity correlation was generated to determine the strength of the relationship of O'Connor's linear equation and Lombardi's nonlinear equation to measured 1RM. Statistical analyses were performed for both leg press and chest press within each predictive equation. Therefore a validity correlation was generated twice for each exercise.

**Results**

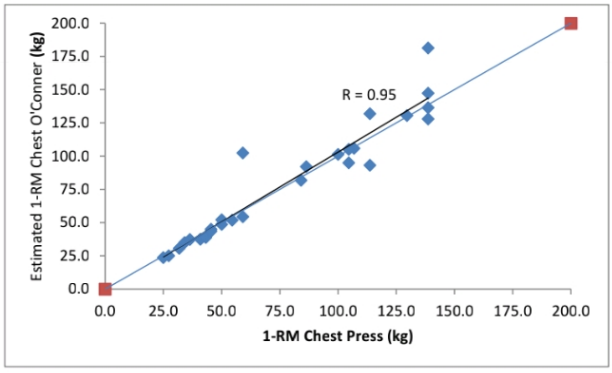



Figure 1. Correlation of actual 1RM and estimated 1RM using O'Connor equation for chest press

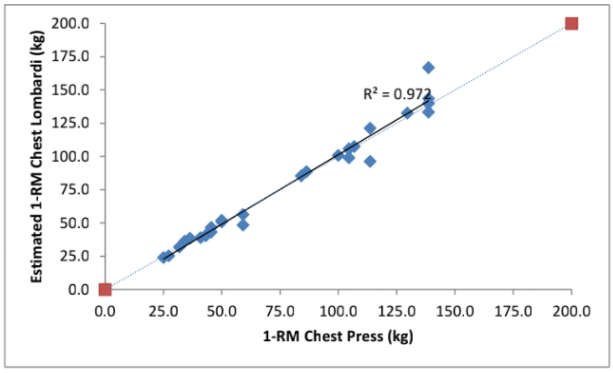
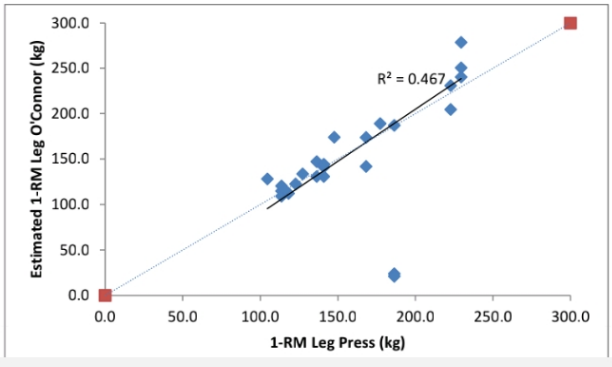



Figure 2. Correlation of actual 1RM and estimated 1RM using Lombardi equation for chest press



Paired t-test were used to determine the mean differences between estimated 1RM from the predictive equations and measured 1RM. Repeated measures analysis of variance (ANOVA) was used to conduct regression analysis. A validity correlation was generated to determine the strength of the relationship of O'Connor's linear equation and Lombardi's nonlinear equation to measured 1RM. Statistical analyses were performed for both leg press and chest press within each predictive equation. Therefore a validity correlation was generated twice for each exercise.

**Results**

*Chest Press*- Repeated measure analysis of variance found no effect for method of 1RM determination. Estimated 1RM was significantly correlated with actual 1RM for the O'Connor equation (R = 0.95) and Lombardi equation (R = 0.99). Paired t-test reported there was not a significant difference between the estimated 1RM from both predictive equations and actual 1RM.

*Leg Press*- Repeated measure analysis of variance found no effect for method of 1RM determination. There was not a significant difference between the estimated 1RM from both predictive equations and 1RM. Estimated 1RM was significantly correlated with actual 1RM for the O'Connor equation (R = 0.92) and Lombardi equation (R = 0.97). Paired t-test reported estimated 1RM from both equations to be significantly higher than actual 1RM.

Table 1. Mean Values of Actual 1RM and Estimate 1RM for Each Exercise

| Chest Press | Leg Press |
|---|---|
| 77.4 ± 40.2 kg (Actual) | 165.2 ± 43.5 kg (Actual) |
| 79.3 ± 44.2 kg (O'Connor) [Linear] | 179.8 ± 63.1 kg (O'Connor) [Linear] |
| 77.7 ± 42.7 kg (Lombardi) [Nonlinear] | 175.6 ± 53.9 kg (Lombardi)[Nonlinear] |