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DEVELOPMENT OF PREDICTION MODELS TO ESTIMATE 1-RM FOR UPPER AND LOWER BODY EXERCISES IN NON-RESISTANCE TRAINED WOMEN

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PURPOSE: The purpose of this investigation was to develop and validate a one-repetition maximum (1-RM) prediction model for the upper and the lower body in non-resistance trained women. **METHODS**: Sixty seven healthy, non-resistance trained women between the ages of 18 and 25 years volunteered for this investigation. The investigation was performed in 2 phases. During phase I, all subjects completed 2 experimental sessions. During the first session, subjects performed a bench press repetition to fatigue (RTF) test with 45 lb and 55 lb. Subjects also performed a leg press RTF with 175 lb and 215 lb. Additional variables that were measured were: body height (in.), body weight (lb), and sum of skinfolds (mm). During the second session, subjects performed a 1-RM bench press and a 1-RM leg press. Phase II of the experiment involved the development and validation of 1-RM prediction models for the bench press and the leg press exercise. **RESULTS:** A stepwise regression analysis was carried out to develop a 1-RM prediction model for the bench press exercise and for the leg press exercise. The initial set of predictor variables considered for the upper body prediction model were: RTF with the bench press, body height (in.), body weight (lb), and sum of skinfolds (mm). The variable selected by the stepwise regression analysis for inclusion in the bench press prediction model was RTF with 55 lb ($r = 0.914$). The model to predict 1-RM bench press was: **Model I: 1-RM bench press = 56.199 + 1.94(RTF55)**. A paired samples t-test indicated that the difference between the mean measured and mean predicted 1-RM was not significant ($p > .05$). The correlation between the measured and the predicted 1-RM values for the bench press was $r = 0.935$. The initial set of predictor variables considered for the lower body prediction model were: RTF with the leg press, body height (in.), body weight (lb), and sum of skinfolds (mm). The variables selected by the stepwise regression analysis for inclusion in the leg press prediction model were RTF with 215 lb and body weight (lb) ($r = 0.798$). The model to predict 1-RM leg press was: **Model II: 1-RM leg press = 145.099 + 2.752 (RTF215) + .618 (body weight)**. A paired samples t-test indicated that the difference between the mean measured and mean predicted 1-RM was not significant ($p > .05$). The correlation between the measured and the predicted 1-RM values for the leg press was $r = 0.695$. **CONCLUSION:** The models developed in this investigation can be used to estimate the upper and/or lower body 1-RM strength of non-resistance trained women. These models will be useful for coaches, personal trainers, and fitness professionals who wish to design strength-training programs to enhance performance and the health-fitness levels of recreationally active females.

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PREFACE

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1.0 INTRODUCTION

The purpose of this investigation was to develop and validate a one-repetition maximum (1-RM) prediction model for the upper and lower body in non-resistance trained women between 18 and 25 years.

1.1 RATIONALE

The participation of women in athletics and/or regular physical exercise programs has increased significantly. Among the many physical activities that women engage in is resistance training. Some of the reasons that women participate in resistance training include increasing their strength as a performance prerequisite for various types of physical activity, preventing osteoporosis, and improving their health and/or physical appearance. In order to develop and implement effective resistance exercise programs it is important to determine the maximal amount of weight a woman can lift, also known as a 1-RM (2). Prediction models are often used to determine a novice exercisers 1-RM, because such a procedure can be easier and safer than actually having the individual perform a 1-RM (2) . Typically, the upper body exercise used to develop prediction models is the bench press and the lower body exercise used to develop prediction models is the back squat.

Prediction models have been developed to estimate the 1-RM of various types of resistance exercises. The bench press is the most frequently examined exercise for 1-RM prediction models (1,5,8,15,20,28,29,31-34,40,41,46), with the back squat (20,34,41,44) and the deadlift (20) also being studied. In addition, exercises such as the leg press (41,43,47) and power clean (34) have been included in prediction models. Unfortunately, many of the prediction models were developed and/or validated using males as subjects (5,28,29,31-34,42,44,46,47) or provide little information about the type of subjects used in the investigation (3,9,19). Some of these investigations have included adolescent males (28,29,31) but most of the investigations have included college age men (5,6,25-27,29,30,32-34,42,44,46,47). There have also been investigations that have included older adults (38,48) and others that include both men and women (1,8,15,20,40,41,43). There are few prediction models that have been developed or validated exclusively for use with women. Horvat, et al. indicated that the development of a prediction model specifically for women is an area that has been understudied (15). Investigations that have estimated the 1-RM of various resistance exercises for women have included both untrained (1,8,25,40,43) and trained women (7,15).

In Horvat, et al. (15), 65 resistance trained female collegiate athletes performed two RTF bench press tests and one 1-RM bench press test. Prediction models were developed and validated from the data that was collected during this investigation (15). These models were used to predict the 1-RM bench press in resistance trained women between the ages of 17 and 23 years. The predictor variables in Horvat, et al. were age, body weight, height, percent body fat, lean body mass (LBM), and repetitions to fatigue (RTF) with 55 lb and 70 lb (15). The investigation found LBM and RTF with 70 lb to be the best predictors of the 1-RM bench press (15).

Cummings, et al. compared three existing 1-RM bench press prediction models and also developed one new 1-RM bench press prediction model in 57 untrained women between the ages of 18 and 50 years (8). The initial set of predictor variables were RTF, height, body mass and structural dimensions which included arm length, upper arm circumference, biacromial breadth (shoulder width), and tricep skinfold (8). The results were used to determine the accuracy of three existing models in predicting the 1-RM bench press of untrained women (8). Of the three existing models, the only model to accurately predict the 1-RM of the women in the Cummings, et al. investigation was by Epley (8). The prediction model that was developed by Cummings, et al. found three variables that explained the greatest variance in the measured 1-RM (8). These variables included the amount weight lifted during the submaximal test, the number of RTF, and biacromial breadth (8). However, using a two-component model that only included RTF and the amount of weight lifted during the submaximal test was also found to be valid in predicting the 1-RM bench press (8). The accuracy of the two-component model was not improved with the addition of the third variable (biacromial breadth) (8). Therefore, it was suggested that the two-component model be used, as measuring biacromial breadth may increase the chance of error (8).

The previously mentioned investigations have employed multiple regression analysis to develop their 1-RM prediction models. Horvat, et al. employed a multiple linear regression analysis to develop 1-RM bench press prediction models (15). A random split case analysis was then used to validate the prediction models that were developed (15). Cummings, et al. employed a forward stepwise regression analysis to develop 1-RM bench press prediction model (8). Similarly, Morales, et al. employed a stepwise multiple regression model (34). Simpson, et al. employed a stepwise multiple linear regression procedure to determine the most statistically significant predictor variables in the investigation (41). A double, cross-validation was then performed on the prediction models that were developed in the Simpson investigation (41).

There has been minimal research and few prediction models developed solely for women of any age and athletic ability. As such, the need to further validate the prediction models that were developed in Horvat, et al. (15) and possibly develop new prediction models appears to be warranted. Establishing bench press prediction models for females who are athletic, non-athletic and/or of various ages would greatly enhance the applicability of 1-RM prediction models. In addition, developing a 1-RM prediction model for the lower body in such cohorts also seems necessary. Prediction models are useful for coaches, personal trainers, and fitness professionals who wish to design strength-training programs to enhance athletic performance as well as health-fitness and leisure physical activity participation in both the competitive and recreationally active female.

Therefore, the present investigation developed and validated a 1-RM prediction model for the upper and the lower body in untrained women. More specifically, this investigation developed and validated a 1-RM prediction model for:

- Healthy, non-resistance trained women between the ages of 18 and 25 years for the bench press and the leg press exercise.

1.2 STATEMENT OF THE PROBLEM

The purpose of this investigation was to develop and validate a 1-RM prediction model for upper and lower body resistance exercises in untrained women. Specifically, this investigation developed and validated a 1-RM prediction model for the bench press and leg press exercise in non-resistance trained women between the ages of 18 and 25 years. The initial set of predictor variables included: RTF (bench press and leg press), body height (in.), body weight (lb), and sum of skinfolds (mm).

2.0 LITERATURE REVIEW

The purpose of this investigation was to develop and validate a 1-RM prediction model for the upper and lower body in non-resistance trained women between 18 and 25 years.

2.1 PURPOSE

The number of women of all ages who participate in resistance exercise training programs has increased in recent years. Often, men and women who weight train have limited knowledge on the proper form and technique necessary for resistance exercise. Many individuals refer to exercise books as a guideline for the proper exercises and lifting techniques. However, such references do not provide the exact training weight that each individual should lift. An effective weight training dosage is typically based on a percentage of the individual's 1-RM. In this regard, charts can be used to predict an individual's 1-RM. The majority of these charts and associated prediction models were designed using males as the research subjects. The availability of having prediction models for women, more specifically for untrained women, may decrease injury risk associated with resistance exercise and provide a guideline to determine the optimal weight to lift when beginning an exercise program. The purpose of this literature review is to define strength testing, discuss previous research related to 1-RM prediction models, and in turn use this information to provide a rationale for the present investigation.

2.2 STRENGTH TESTING

Strength testing may be conducted for several purposes such as identifying an individual's strengths and weaknesses, monitoring progress, and providing feedback on performance (37). Some of the more common mechanisms in which strength is measured include free weights and resistance exercise machines (41). Strength testing can occur in either a laboratory or a field setting (3). Laboratory testing often uses isokinetic dynamometry to determine a variety of measures such as absolute and relative strength, absolute and relative power, and leg/arm strength dominance (49). Although laboratory testing is reliable and valid, it is also often impractical, as it is costly and time consuming (3). Therefore, this method of strength assessment is primarily applicable when testing the elite athlete but not the untrained individual (3). Field-testing provides a desirable alternative method to assess strength in the untrained population (3). The benefit of field-testing is that it requires minimal time, money, equipment, and it is easily conducted (3). Frequently used field-tests include exercises such as the bench press, back squat, and leg press to determine 1-RM (3).

Muscular strength is defined as the ability to exert maximal muscular force at any given speed for 1-RM (2,12,13,50). Because resistance exercises can be performed at differing speeds, there are variations in strength measured for a given type of exercise (12,50). Low speed muscular strength is measured by exercises such as the bench press and squat, as these exercises are performed at a low movement speed (12,50). High-speed strength, or explosive strength, is measured by exercises such as the power clean, vertical jump, or shot put throw (12,50). These exercises require that maximal force be produced in minimal time (12,50). Often, the terms strength and power are misused (14). Power is defined as "the time rate of doing work" (13,14). Work is defined as the product of force exerted on an object and the distance in which the object moves (13,14). Mathematically, work equals force multiplied by distance ($W = F \times D$) (13,14).

Power equals work divided by time (P = W/T), which equals force multiplied by distance divided by time (P = F x D/T), or force multiplied by velocity (P = F x V) (13,14). Sophisticated equipment is necessary to accurately measure an individual's power (13). Strength, not power, will be the measure discussed in this review.

Various exercises are used to improve the strength of an individual. These exercises are categorized according to changes in muscle length during the action phase of the movement (50). Muscular strength is typically measured using dynamic exercises (3,41) but can also be measured using static exercises (3). Dynamic, or isotonic exercise, is the movement of a body part against a constant external force (3,36). The external force or resistance may be gravity, a dumbbell, barbell, or weight machine (36). Although the external resistance is constant, the internal resistance may change (50). Internal force is the force applied from one part of the body onto another, such as the force of a tendon onto a bone (50). Dynamic exercises often include concentric and eccentric movements (50). Concentric movements occur when the muscle exerts force on the bone while shortening and eccentric movements occur when the muscle exerts force on the bone while lengthening (50). Muscular strength is often measured by having an individual perform a dynamic exercise such as a 1-RM (3,8,41). The bench press is an example of a dynamic exercise that is used to test muscular strength (8). Static, or isometric exercise, is when the muscle remains at a constant length throughout the exercise (50). Static exercises measure muscular strength against a fixed, non-moving resistance (3), Although static exercises are inexpensive and relatively easy to perform, they are less frequently used (3). This is because static exercise training will primarily produce gains only at the specific joint angle that is involved (50). In addition, there is often significant pain associated with this method of training (50).

Both absolute muscular strength and relative muscular strength can be measured during testing (50). Absolute muscular strength measures an individual's maximal strength without taking into account differences in body weight (14,50) or sex (10). Relative muscular strength is a measure of an individuals muscular strength that is based on a proportion of the total body weight (14,50), LBM or muscle cross sectional area (14). The following equation can be used to determine an individuals relative strength: relative strength equals absolute strength divided by body weight (50).

Genetic influences (3) and gender differences (8) have also been considered when testing an individual's strength while using a RTF method (3). An individual's physical and mental profile as influenced by genotype may influence their performance (3). Such genetically determined factors as predominant muscle fiber type, muscle to tendon ratio, and limb length may affect the performance (3).

An individual's structural dimension has been considered when developing models to predict 1-RM strength. Mayhew, et al. examined the relation between anthropometric dimensions and strength performance in collegiate football players (30). This investigation found that arm size and percent body fat significantly related to the 1-RM when testing trained athletes in the bench press, back squat, and deadlift exercise (30). In a separate investigation, Mayhew, et al. examined the relation between anthropometric dimensions and bench press performance in college age males who were not involved in collegiate athletics (26). A multiple regression analysis found that upper arm cross sectional area, percent fat, and chest circumference were the best predictors of bench press strength (26). Following development of the model, a cross validation was performed using a group of untrained college males as well as a group of resistance trained college males (26). The results indicated that the 1-RM prediction models underestimated the bench press strength in those subjects who were resistance trained (26).

2.3 METHODS FOR ESTIMATING 1-RM

In order to develop and implement resistance exercise programs for women, it would be practical if a model were available to predict the maximal amount of weight a woman can lift for 1-RM. Prediction models are often used to determine novice exercisers 1-RM, as they can be easier and safer than actually having the individual perform a 1-RM (2) . One of the main predictor variables used in the development of prediction models is the score derived from the RTF test. RTF tests measure muscular endurance; however, there is a strong well established relation between muscular strength and muscular endurance (3). Therefore, a RTF model can be used to predict muscular strength (3). Typically, the upper body exercise used in the prediction model is the bench press and the lower body exercise used in the prediction model is the back squat or leg press. Unfortunately, the majority of models used to predict the 1-RM for various muscle groups were developed and/or validated using men as subjects (5,28,29,31-34,42,44,46,47). Of the comparatively few studies that have focused on women, models have been developed to predict leg strength (1), leg power (43), and upper body strength (1,7,8,15,25). A number of investigations have also tested the accuracy of existing models in predicting the 1-RM bench press in women (18,20,40). The purpose of the following section of the literature review is to examine previous research that has developed/validated prediction models for testing the 1-RM in various exercises.

2.4 COMMONLY USED PREDICTION MODELS FOR MALES

As previously stated, the majority of models used to predict the 1-RM for various muscle groups are developed and/or validated using men as subjects (5,28,29,31-34,42,44,46,47). Prediction models for college age male athletes primarily employ the bench press (5,6,20,26,29,32-34,42,46), squat (20,34,47), and deadlift (20); with the bench press being the most frequently studied.

2.4.1 Traditional Prediction Methods

One of the more popular prediction models for collegiate and professional football players employs the bench press RTF test with 225 lb (32,42). The RTF test requires the subject to lift a predetermined weight (i.e.: 225 lb) as many times as possible, while using proper form. The test ends when the individual is no longer able to complete a repetition owing to fatigue. The total number of successfully completed repetitions is the RTF score. There are many prediction models available for this bench press test (3,19,32,46). The models that predict a 1-RM bench press using the 225 lb RTF method have also been tested for their validity in several investigations (5,33,46).

Chapman, et al. examined the validity of the 225 lb RTF bench press test as a sub maximal estimate of the 1-RM (5). Chapman, et al. compared five prediction models that are used to estimate the 1-RM bench press (5). The models were valid for predicting the 1-RM in most trained collegiate football players when fewer than 10 repetitions were performed (5). When more than 10 repetitions were performed, the prediction models were not as accurate (5). It was suggested that a new model with a greater set weight be developed for football players who perform more than 10 repetitions (5) . Mayhew, et al. examined the accuracy of prediction models that use the RTF method by testing the 1-RM of collegiate football players (33). In this investigation, athletes performed both a 1-RM and a RTF test with 225 lb (33). Results indicated that only two of the nine models that were examined estimated strength values that were statistically similar to the actual 1-RM, with the NFL model being the most accurate (33). This investigation also noted a decrease in the accuracy of the prediction models when the number of repetitions was greater than ten (33). This may be explained by the fact that the majority of prediction models assumed linear rather than curvilinear functions, which seems to result in less accuracy when more than 10 repetitions are performed (3). Similarly, in an investigation by Whisenant, et al. the validity of 11 existing 1-RM prediction models was tested (46). Collegiate football players performed a RTF test with 225 lb and a 1-RM (46). The RTF was then placed into each of the 11 existing models to determine if the value obtained from the prediction model was similar to that of the measured 1-RM (46). The predicted 1-RM from 7 of the 11 models was similar to the measured 1-RM when less than 10 repetitions were performed, while 5 of the 11 models were more accurate when greater than 10 repetitions (10-20 repetitions) were performed (46). Whisenant, et al. also devised a new prediction model that employed not only RTF and structural measures as predictor variables, but also subject demographics.(46) The predictor variables included height, weight, percent body fat, fat free weight, race, and age (46). Race was the only variable that increased the explained variance in the models (46). There is a need for further research in the area of demographic and structural predictors as well as the appropriate number of repetitions required for the prediction model (46).

2.4.2 Anthropometric Measurements

Mayhew, et al. used various anthropometric dimensions to compare several NFL 225 lb prediction models for 1-RM strength in collegiate football players (27). Subjects performed both a 1-RM bench press and a RTF test with 225 lb (27). Anthropometric measurements included arm and chest circumference, arm length, drop distance (distance from the bar to the sternum when the subject is holding the bar with arms extended while supine on the bench), and skinfold measures (27). RTF was the best predictor of the 1-RM in this investigation (27). The anthropometric dimensions did not explain a significantly greater amount of variance in the 1-RM than when using the RTF value alone (27).

2.4.3 Non-traditional prediction methods

Although performing RTF at 225 lb is a commonly used procedure, there have been other methods and other muscle groups employed to predict the 1-RM for the bench press. Mayhew, et al. used a one-minute push up test to predict the 1-RM bench press in college males (23). The prediction correlation was not high (r=0.47) in this investigation (23). The results indicated that the push up test was not highly correlated with the 1-RM bench press in college males (23). Grip strength has also been correlated with a 1-RM bench press in untrained and trained college age males and females (4). The correlation was high (r=0.76 males, r=0.74 females) between the grip strength and the bench press 1-RM in the untrained male and female groups (4). Pearson-Product-Moment correlation coefficients for grip strength and bench press did not differ between the male and female untrained groups (4). However, the correlation between the grip strength and the bench press 1-RM was lower in the trained male and female athletes (r values as follows: 0.65 for the power lifters, 0.56 for the women's soccer, 0.44 for the football players) (4). Results from this investigation suggest that the existence of a significant correlation between grip strength and 1-RM bench press depends on the type of resistance training typical of the individual being tested (4).

2.4.4 Predicting 1-RM: more or less than 10 repetitions

As previously indicated, there is some debate as to the number of repetitions that must be completed to accurately predict individual's 1-RM using regression models. Some investigations have suggested that less than10 repetitions are required to accurately predict an individuals 1-RM (3) while other investigations have suggested that it does not matter how many repetitions an individual completes, as long as the proper prediction model is used (31). Mayhew, et al. performed a RTF investigation using adolescent boys who were participating in a weight training class (31). On the first day, the boys performed a 1-RM bench press (31). On the second day, the boys performed a RTF test with a weight that they chose (31). The two tests were separated by several days (31). There were four different models used to predict the 1-RM from the repetitions completed at the various weights (31). The RTF ranged from 2 repetitions to 20 repetitions (31). The curvilinear equation by Mayhew, et al was the most accurate (24). This model predicted the subject's 1-RM to within 0.7 lb of the measured 1-RM (31). The correlation coefficient was r = 0.96 (31). This investigation suggested that the use of a submaximal test where the subject performs between 8-20 repetitions is much safer for adolescent boys (31).

2.4.5 Lower body prediction models

Using the cross-model paradigm, the leg press exercise has been used to predict squat performance (47). Willardson, et al. used a 10-RM leg press test to predict the 10-RM squat in novice and experienced young males (47). Predictors included limb length, body mass, leg press mass, and squat mass (47). For the novice and experienced groups, leg press mass was a significant predictor of the squat mass, but limb length and body mass were not (47). This investigation was unique in that it predicted a 10-RM as opposed to a 1-RM strength measure (47). Willardson, et al. suggests that this is a much safer and realistic method of determining an individual's strength, as most individuals who begin an exercise program are more likely to perform 10 repetitions and less likely to perform a 1-RM (47). It is important to note that Willardson, et al. also suggest that future research include a comparison of 1-RM prediction accuracy between males and females as well as examining the relation between anthropometric measures and muscular strength in females (47).

2.5 COMMONLY USED PREDICTION MODELS FOR FEMALES

There are very few 1-RM prediction models specifically designed and validated for females. Horvat, et al. developed and validated 1-RM prediction models for collegiate female athletes using the bench press (15). The subjects in this investigation performed a RTF test using absolute weights of 55 lb and 70 lb (15). In addition, subjects performed a 1-RM bench press test (15). Of the four models developed, the model using LBM and RTF at 70 lb best estimated the 1-RM (r =0.916) (15). While the Horvat, et al. investigation indicated that these models are valid for trained college age females, the models have not been validated for use with other age groups or untrained females (15). Cummings, et al. examined the accuracy of predicting the 1-RM bench press of untrained females between the ages of 18 and 50 years using three common RTF 1-RM bench press regression models (8). A new prediction model was also developed using both performance and structural variables to predict the 1-RM of these women (8). Of all of the variables considered, RTF and submaximal weight served as the best predictors for the newly developed model (8). Results also indicated that only one of the existing 1-RM prediction models (Epley) did not significantly underestimate the measured bench press (8).

As in studies involving male subjects, other measures beside the bench press have been used to predict 1-RM for females of various ages. The one minute modified push-up test has been used to predict the 1-RM bench press in college age women (25). However, there was not a high correlation between the number of push-ups completed and the 1-RM bench press in this investigation (25). An investigation that compared the grip strength of untrained and trained males to the 1-RM bench press performance also compared the grip strength of untrained and trained females to their 1-RM bench press performance (4). As with male subjects, there was a high correlation (r = 0.74) between grip strength and bench press performance in the untrained females (4). There is also new research that has examined the effectiveness of a chest pass in predicting the strength and power of female netball players (7). This investigation compared a seated chest press throw (using a 400-g netball) to a 10-kg bench press throw using a smith machine (7). The bench press throw was used to determine a variety of measures, including maximal strength (7). The netball throw was shown to be a reliable, valid, inexpensive, and easy method of assessing strength and power (7). The findings suggest the netball throw as an effective sport specific method of determining the strength and power of netball players (7). However, the researchers have indicated that further investigation is needed regarding generalization of this approach to other sport types (7).

2.6 COMMONLY USED PREDICTION MODELS

Several 1-RM prediction models have been developed through existing research. Table 2.1 (20) includes seven of the more common prediction models.

Table 2.1 Prediction Models for 1-RM

Author	**Equation**
Brzycki (3)	1-RM=100 x rep wt/(102.78-2.78 x reps)
Epley (9)	1-RM=(1+.0333 x reps) x rep wt
Landers (19)	1-RM=100 x rep wt/(101.3-2.67123 x reps)
Lombardi (21)	1-RM=rep wt x (reps) **.1
Mayhew et al. (24)	1-RM=100 x rep wt/(52.2+41.9 x exp [-.055 x reps])
O'Conner et al.(35)	1-RM=rep wt (1 + .025 x reps)
Wathan (45)	1-RM=100 x rep wt/(48.8 + 53.8 x exp [-.075 x reps])

The notation ** indicates exponentiation

Brzycki developed a prediction model with the reasoning that there is a linear relation (up to 10 repetitions) between an individual's 1-RM and their RTF (3). It was suggested that most individuals lift 75% or their 1-RM when they perform exactly 10 repetitions at a set weight (3). Therefore, if an individual can lift 200 lb for one repetition, then that individual can lift 150 lb for exactly 10 repetitions (75% of 200lb) (3). Based on this assumption, Brzycki developed a chart using a mathematical equation that predicts an individual's 1-RM according to how many times (up to 10 repetitions) that they lift a set weight (3).

Landers developed a chart that also appears to be based on a mathematical equation (19). Very little methodological information was presented by Landers, as there is only a prediction chart provided in the publication (19). The chart can predict an individual's 1-RM ranging from 105 lb to 700 lb (19).

Mayhew, et al. developed a model by testing both males and females with various amounts of training experience (24). The subjects in this study performed a 1-RM test as well as a one-minute repetition bench press at a predetermined weight between 55-95% of their 1-RM (24). College age males and females, high-school males (trained and untrained), and collegiate football players were used to develop and test the model (24). The model was developed using the combined results of both the men and the women because the gender specific curves were not significantly different ($p>.05$) in either slope or intercept between the two groups (24). The model developed in this investigation is exponential, and the repetitions were limited to a maximum of 15 (24).

2.7 EFFECTIVENESS OF PREDICTION MODELS

A significant number of studies have compared the effectiveness of existing prediction models. LeSuer, et al. examined the accuracy of seven of the more commonly used prediction models for untrained males and females (20). Subjects performed a 1-RM and a RTF test for the bench press, squat, and deadlift (20). Results of the RTF test were used to predict the 1-RM using the seven models listed in Table 2.1. Although the correlation between the predicted and measured 1-RM was high ($r = 0.95$) in all of the exercises, most of the models underestimated the measured 1-RM (20). When predicting the 1-RM bench press, the Mayhew, et al. and the Wathan models were the only models that produced an predicted value that was not significantly different from the measured 1-RM (20) . All other models underestimated the measured 1-RM by 2.2-5.4 lb (20). When predicting the 1-RM of the back squat, the Wathan model was the only model for which the predicted 1-RM that was not significantly different from the measured 1-RM (20). All other models underestimated the 1-RM by 4.6-16.5 lb (20). When predicting the deadlift, all models underestimated the 1-RM by 22.2-33.7 lb (20).

Wood, et al. (48) compared the same seven models that were used in LeSuer et al.(20) to predict 1-RM strength. However, in Wood, et al. the subjects were older (average age of 53 years) males and females (48). These subjects performed various exercises on resistance machines (48). Subjects were given a predetermined weight to lift for as many repetitions as possible (48). This weight ranged from between 50-90% of their 1-RM (48). The Epley (9) and Wathan (45) formulas were the best predictors (13-22% error) of the measured 1-RM in all of the exercises performed by the men and women in this investigation (48).

Morales, et al. tested 23 resistance trained males in the bench press, squat, and power clean (34). All subjects performed a 1-RM in each of the exercises prior to their repetition tests (34). The tests included performing as many repetitions as possible with varying percentages (70-95%) of the subject's 1-RM (34). The best predictor in the bench press was repetitions completed at 95% of 1-RM (34). The best predictor in the squat was repetitions completed at 80% 1-RM (34). The best predictor in the power clean was repetitions completed at 90% 1-RM (34). The findings indicated that separate prediction models are required according to the exercises being performed (34). In addition, as the percentage of the 1-RM decreases, so does the accuracy of predicting an individual's 1-RM based on the number of repetitions completed (34).

Ware, et al compared a few existing models used to predict an individuals 1-RM (44). College age male football players performed a 1-RM in the bench press and squat, as well as a

RTF at approximately 70% of their 1-RM (44). At this intensity, the average number of repetitions completed was 13.9 for the bench press and 17.4 for the squat (44). The Mayhew, et al. model underestimated the 1-RM bench press, and Epley, Lander, and Brzycki models all overestimated the 1-RM bench press (44). All models overestimated the squat 1-RM (44).

Mayhew, et al. examined existing RTF models to predict the 1-RM of high school age male athletes (28). There were ten existing prediction models used during this investigation, six of the models were linear, four were curvilinear (28).

An investigation by Kim, et al. used the YMCA bench press test to determine if cadence influenced prediction accuracy of the 1-RM bench press in young men and women (18). The subjects performed a 1-RM bench press and a muscular endurance test using a cadence of both 30 and 60 repetitions per minute (18). Anthropometric measurements were also recorded (18). The women performed more repetitions at the slower cadence, with both methods being good 1-RM predictors (18). There was no difference in the repetitions performed between the two cadences for the men (18). Anthropometric measurements did not improve the predictive power of the model (18).

2.8 SUMMARY

In summary, there is a need for the development of prediction models for non-resistance trained females. The majority of the existing models are designed for males, with many of these models being specific to the athletic population. There has been little research on prediction models specifically developed for women. Prediction models developed specifically for women will be useful for coaches, personal trainers, and fitness professionals who wish to design strength-training programs and to enhance the health-fitness levels in the recreationally active female.

3.0 METHODS

The purpose of this investigation was to develop and validate a 1-RM prediction model for the upper and lower body in non-resistance trained women between 18 and 25 years. All investigational procedures were approved by the Institutional Review Board (IRB) at the University of Pittsburgh. Written informed consent was obtained from all volunteers prior to participation in this investigation.

3.1 SUBJECTS

Sixty-seven women ranging in age from 18 and 25 years volunteered to participate as subjects in this investigation. No subject was actively participating in a resistance exercise program for at least six months prior to the start of the investigation. Subjects were permitted to be actively involved in aerobic activity and/or recreational sports. Women who were inter-collegiate athletes, clinically obese-as defined by the ACSM (11), and/or pregnant were excluded from this investigation. Subjects did not have orthopedic, cardiovascular, neuromuscular and/or metabolic contraindications to exercise testing.

All subjects completed the Physical Activity Readiness Questionnaire (PAR-Q) (Appendix A). Prospective subjects who answered "yes" to any of the questions were required to obtain medical clearance if they wished to participate in the study. Any prospective subjects who answered "yes" to any of the questions in the PAR-Q and did not obtain medical clearance were not permitted to participate in the study. The PAR-Q asks questions regarding heart conditions, chest pains, severe dizziness and/or fainting, blood pressure, bone or joint problems, and any other condition that may prohibit exercise participation. Subjects who answered “no” to all questions were regarded as apparently healthy individuals and were eligible to participate in the investigation. Using the American College of Sports Medicine (ACSM) guidelines, such individuals were classified as asymptomatic and apparently healthy with no more than one major coronary risk factor (17).

Resistance exercise training experience of the subjects was established by asking the subject if they have ever resistance trained and if so, when was the last time. If the subject had been involved in a resistance exercise training program in the past six months, they were excluded from the study.

Prior to participation, each subject provided written informed consent as approved by the IRB of the University of Pittsburgh (Appendix B). The IRB described the testing procedures, risks, and benefits of participating in this investigation. Each subject was informed of her right to withdraw from participation at any time during the investigation. If a subject was willing to participate in the investigation, she was asked to sign the consent document.

3.2 RECRUITEMENT PROCEDURES

Potential subjects were recruited for this investigation by displaying informational flyers throughout the University of Pittsburgh campus. This investigation was also announced during the first week of activity classes in Trees Hall and The Peterson Event Center for the spring and summer semesters (2007). Each subject received $20 for their participation in the investigation.

3.3 RESEARCH DESIGN

This investigation employed a cross-sectional correlation design. The investigation was performed in two phases. Phase I of the investigation included two sessions. There were at least two days between the first session and the second session. For any subject who reported DOMS (delayed onset muscular soreness), the second session was postponed by approximately two days to allow for a full recovery. Phase II of the investigation included the development of the 1-RM prediction model for the bench press and the leg press exercise. Phase II is discussed in section 3.4.

3.3.1 Phase I, Session 1

There were 67 women who participated in Phase I, Session 1. During session 1, a RTF test for the bench press and the leg press exercise was performed. The same bench press weight and the same leg press weight was used for all subjects, as there is less prediction error than when the subject is permitted to choose her weight. In addition, using a fixed weight in the model has greater practical application. During session 1, subjects were randomly assigned to perform a RTF test with either the lighter bench press weight (45 lb) or the heavier bench press weight (55 lb) and either the lighter leg press weight (175 lb) or the heavier leg press weight (215 lb). After completing the RTF tests, there was a 15 minute break during which time all structural measurements were recorded. Following the break, subjects performed a second RTF test for the bench press and the leg press at the opposite weight of what they performed during the first RTF test.

Session 1 included the following, in order:

1. Informed consent,
2. PAR-Q,

3. Orientation to the bench press exercise and the leg press exercise,
4. Warm up,
5. A RTF test for the bench press and for the leg press at a set lighter weight or heavier weight,
6. Fifteen minute rest. Height (in.), weight (lb), sum of skinfolds (mm), and a pregnancy test were performed during the 15 minute rest,
7. A second RTF test for the bench press and for the leg press at a set lighter weight or heavier weight, opposite of what was performed during the first RTF test.

3.3.2 Phase I, Session 2

There were 67 women who participated in Phase I, Session 2. During Session 2, a 1-RM for the bench press and the leg press exercise was performed. The design for Phase I (Sessions 1 and 2) is shown in Figure 3.1.

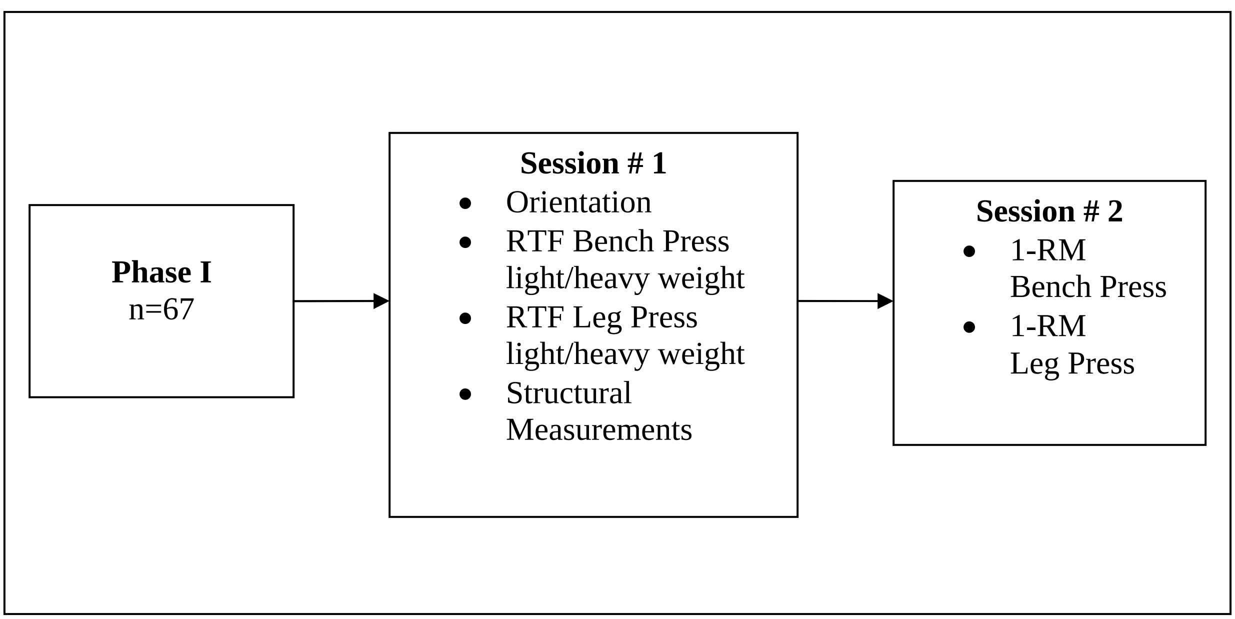

Figure 3.1 Phase I Data Collection

3.4 MODEL DEVELOPMENT AND VALIDATION

During Phase II of the experiment, a RTF protocol was used to develop a 1-RM prediction model for the bench press and the leg press exercise. In this protocol the dependent variable for both the bench press and the leg press prediction models was the exercise specific 1-RM. The principle predictor variable was the RTF using a specified weight. Additional predictor variables were body height (in.), body weight (lb), and the sum of skinfolds (mm). These predictor variables were chosen as they have been shown to explain significant variance in upper and lower body 1-RM strength for men (18,26,27,30,46,47) and women (8,15,18). The predictor variables were entered into a multiple regression model to estimate the 1-RM for both the bench press and the leg press exercise.

3.4.1 Bench Press

Of the original 67 subjects, 58 met the criteria necessary to be included in either the development or the validation of the bench press 1-RM prediction model. Of the 58 subjects, 18 were randomly selected to be included in the validation of the 1-RM prediction model. The remaining 40 subjects were included in the development of the 1-RM prediction model.

3.4.2 Leg Press

Of the original 67 subjects, 54 met the criteria necessary to be included in either the development or the validation of the leg press 1-RM prediction model. Of the 54 subjects, 18 were randomly selected to be included in the validation of the 1-RM prediction model. The remaining 36 subjects were included in the development of the 1-RM prediction model. The design for Phase II is shown in Figure 3.2.

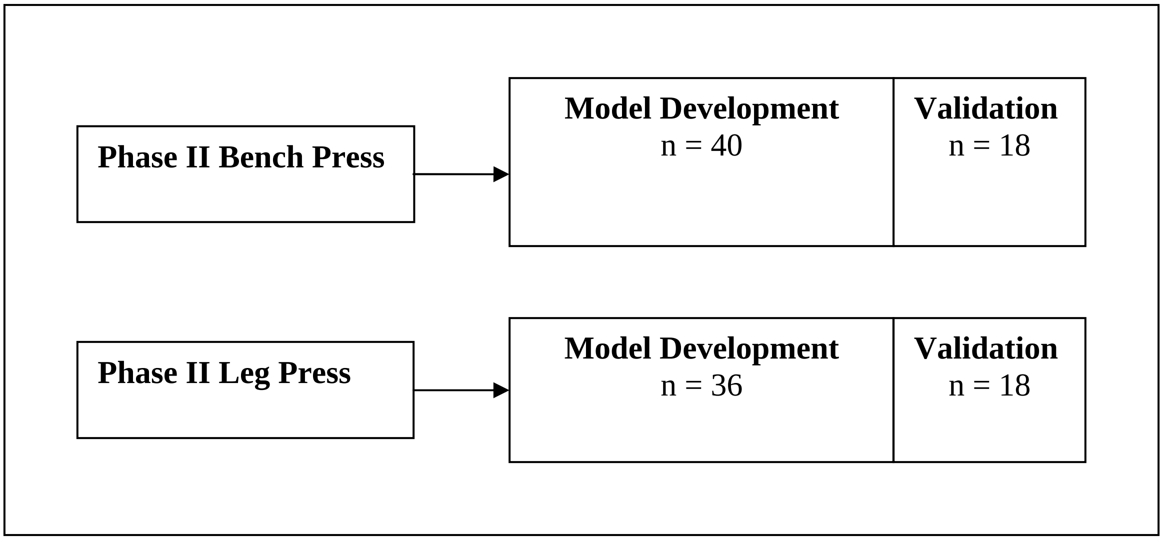

Figure 3.2 Phase II Model Development and Validation

3.5 ASSESSMENT PROCEDURES (PHASE I)

3.5.1 RTF Bench Press and Leg Press (n=67)

All subjects completed a RTF for both the bench press and the leg press at a predetermined absolute weight. The absolute weights that were chosen in the current investigation were based on pilot work, the experience of the investigator, and prior research. It is recognized that the international weight measurement for scientific purposes is customarily expressed in metric units. However, pounds as opposed to kilograms are used throughout the manuscript as the unit of measure for both body weight and the amount of weight lifted. The use of this measurement provides consistency with previously published 1-RM prediction models and it is the unit of measure most commonly employed in developing general weight training programs.

All subjects were familiarized with the resistance exercise equipment and the exercises to be performed. The resistance exercises were the flat bench press and the leg press. Subjects were instructed regarding performance of these exercises according to the National Strength and Conditioning Association (NSCA) guidelines (2). This ensured the exercise was performed using the proper form. Performing the flat bench press and the leg press in a slow, controlled manner was emphasized and monitored throughout the investigation. Both the bench press and the leg press exercises used the five point body contact position (2). The five points involve anatomical contact between either the bench or the floor. The contact points are the back of the head, upper back/shoulders, lower back/buttocks, and both feet. These contacts create both a stable lifting posture and the greatest back support. To further ensure safety, a spotter was present during every lift.

Following the familiarization with the exercises to be performed, and prior to the RTF tests, all subjects were required to complete a general warm-up. Subjects could either ride a stationary cycle ergometer for 5 minutes at a pedal rate of 50 revolutions per minute or walk on a treadmill for 5 minutes at a speed of 3.0 mph and a grade of 0%. The warm-up also consisted of both dynamic and static stretching. Static and dynamic stretching included the following muscles: pectoral major and minor, latissimus dorsi, shoulder girdle, triceps, quadriceps, hamstrings, hip abductors and adductors, gastrocnemius, and soleus. Each static stretch was performed one time and held for 30 seconds.

3.5.2 Experimental Variables

The following variables were measured during session # 1:

Height: Body height was measured in inches on a calibrated physicians scale. Subjects removed their shoes prior to the height measurements. Socks, shorts, and t-shirts were worn during these measurements.

Weight: Body weight was measured in pounds on a calibrated physicians scale. Subjects removed their shoes prior to the weight measurements. Socks, shorts, and t-shirts were worn during these measurements.

Body composition: Sum of skinfolds was determined by double thickness, subcutaneous adipose (ie: skinfold) measures. The skinfold measurement procedure is easy to administer, inexpensive and practical, increasing generalization of findings (17). All skinfold measurements were taken on the right side of the body using a Lange skinfold caliper. The tester sequentially rotated measurement sites, taking the measurement within one to two seconds after lifting the fold for the selected area. A three-site formula was used to predict percent body fat. The measurement sites were the triceps, suprailium, and thigh. Each site was measured at least two to three times. To be considered acceptable, at least two of the measurements taken (at each site) needed to be within one to two mm of each other (17). Otherwise, the measurements were repeated. The description of each skinfold measurement is as follows (17): The triceps measurement is a vertical fold on the posterior midline of the upper arm, halfway between the acromion and olecranon processes, with the arm held freely to the side of the body. The suprailiac measurement is a diagonal fold in line with the natural angle of the iliac crest taken on the anterior axillary line immediately superior to the iliac crest. The thigh measurement is a vertical fold on the anterior midline of the thigh, midway between the proximal border of the patella and the inguinal crease (hip). Percent body fat was determined by using the Jackson, et al. chart: Percent fat estimates for women using the sum of triceps, suprailiac, and thigh (16).

RTF Flat Bench Press: The same weight was used for all 67 subjects during the flat bench press RTF tests. The flat bench press that was used in this study was the standard free weight flat bench press used in exercise facilities (Appendix C). The bench-press bench includes an integral bar rack that can be adjusted for use at varying heights. Based on pilot work, the weights chosen were as follows: the lighter RTF weight was 45 lb and the heavier RTF weight was 55 lb. Subjects were instructed to perform as many repetitions as they could. The test ended when the subject could no longer complete the repetition using proper form, as determined by the investigator. The RTF test score was the number of repetitions completed for each specific exercise. These scores were recorded and used as predictor variables in the development of the 1-RM models for the bench press and leg press.

Subjects were instructed to lay supine on the bench with their feet firmly placed on the floor and their buttocks, shoulders, and head flat against the bench (i.e. five point positions). The edge of the bar supports were even with the subjects eyes, the hands were placed shoulder width apart in a pronated position (overhand grip), and the wrists remained straight, locked and in line with the elbows throughout the movement. The weight was slowly lowered to touch the chest at nipple level, followed by an upward push of the weight until the elbows were fully extended. A pause at the end of the downward phase was not required. However, bouncing the bar off of the chest was not permitted. The five-point position was maintained throughout the movement. Improper lifts were discounted.

RTF Leg Press: The same weight was used for all 67 subjects during the leg press RTF tests. The leg press that was used in this investigation is a Cybex Seated Leg Press machine (Appendix D). Based on pilot work, the weights chosen were as follows: the lighter RTF weight for the leg press was 175 lb and the heavier RTF weight for the leg press was 215 lb.

Subjects were instructed to sit with their lower back, hips, and buttocks pressed against the pads of the machine. Feet were placed firmly on the leg press platform, with feet shoulder width apart (or wider), toes facing straight or slightly outward, and knees at 90° flexion. During the upward phase of the movement, subjects were instructed to extend the hips and knees at the same rate while keeping the back flat, buttocks in contact with the seat, feet flat on the platform, and knees in line with feet. The upward phase was complete when the subject achieved full extension at the hips and knees. Locking the knees while at full extension was not permitted at any time during the movement. During the downward phase of the movement, subjects were instructed to keep their hips and buttocks on the seat and their back flat against the back pad. Feet remained on the platform, with knees in line with the feet. The hips and knees were slowly flexed until the thighs were parallel to the platform (90° flexion at knees). Bouncing or rapid downward acceleration, flexing the torso and rounding the back was not permitted at any time during the movement. After the exercise was complete, the subject returned the weight to the starting position, removed their feet from the machine, and stepped off.

The following prediction variables were measured during session # 2:

1-RM Bench Press and Leg Press: A 1-RM for both the bench press and leg press was measured using the National Strength and Conditioning Association (NSCA) testing protocol (2). In addition to the general warm-up, subjects performed an exercise specific warm-up with a light resistance for the bench press and the leg press. The bench press and leg press warm-up was performed with an exercise specific weight that could be lifted easily for five to ten repetitions. After a one minute rest, another warm-up resistance was performed for three to five repetitions. This warm-up used a weight that was 5-10% greater for upper body and 10-20% greater for lower body resistances that was performed in the first warm-up. A two-minute rest followed. A two to three repetition near-maximum resistance was performed using the above progression (i.e. add either 5-10% weight for bench press or 10-20% weight for leg press exercises). Following a two to four minute rest, a 1-RM was attempted by increasing the weight of the previous attempt by adding either 5-10% of the weight for bench press or 10-20% of the weight for leg press exercises. If the subject successfully lifted the weight with the proper from, as determined by the investigator, then the above procedure with additional weight was repeated until a 1-RM was achieved. If the subject was unsuccessful, the weight was decreased by either 2.5-5% for bench press or 5-10% for leg press exercises. The procedure was repeated until a 1-RM was achieved. The 1-RM was determined within five lift attempts. A failed lift was one in which proper form was not achieved. In the bench press, a failed attempt was the result of the subject not bringing the bar all the way down to the chest, bouncing the bar off of the chest, or not pressing the weight all the way back up to the starting position with elbows in 180° extension. For the leg press, a failed attempt was the result of the subject not pressing the weight all the way out with hips and knees fully extended or not maintaining proper back position.

3.6 STATISTICAL ANALYSIS

The SPSS Windows 15.0 statistical package was used for data analysis during Phase II of this investigation. The same statistical procedures were followed for both the bench press and the leg press exercise. Statistical significance was set at the $p < .05$ level. Descriptive characteristics of the subjects were presented as means and standard deviations. A stepwise multiple regression analysis was used to develop a 1-RM prediction model for both the bench press and the leg press exercise. A matrix showing correlations among the predictor variables as well as the correlation between each predictor variable and the criterion variables was presented for descriptive purposes.

3.6.1 Bench Press Data

Of the 58 subjects who were included in Phase II, 18 subjects were randomly selected to validate the 1-RM bench press prediction model. The remaining 40 subjects were used in the development of the 1-RM bench press prediction model. The initial predictor variables considered for the prediction model were: RTF with 45 lb and RTF with 55 lb, body height (in.), body weight (lb), and sum of skinfolds (mm). The criterion variable was the 1-RM for the bench press (lb). The only predictor that explained a significant amount of variance in the exercise specific 1-RM was RTF with 55 lb. As such, RTF with 55 lb was retained in the final prediction model.

3.6.2 Leg Press Data

Of the 54 subjects who were included in Phase II, 18 subjects were randomly selected to validate the 1-RM leg press prediction model. The remaining 36 subjects were used in the development of the 1-RM leg press prediction model. The initial predictor variables considered for the prediction model were: RTF with 175 lb and RTF with 215 lb, body height (in.), body weight (lb), and sum of skinfolds (mm). The criterion variable was the 1-RM for the leg press (lb). The predictors that explained a significant amount of variance in the exercise specific 1-RM were RTF with 215 lb and body weight (lb). As such, RTF with 215 lb and body weight (lb) was retained in the final prediction model.

4.0 RESULTS

The purpose of this investigation was to develop and validate 1-RM prediction models for the upper body and lower body using non-resistance trained women (18-25 years old). The upper body exercise was the bench press and the lower body exercise was the leg press. The initial predictor variables considered for the upper body prediction model were: repetitions to fatigue (RTF) with the bench press, body height (in.), body weight (lb), and sum of skinfolds (mm). The initial predictor variables considered for the lower body model were: RTF with the leg press, body height (in.), body weight (lb), and sum of skinfolds (mm).

4.1 DESCRIPTIVE CHARACTERISTICS

4.1.1 Bench Press

Of the original 67 subjects recruited, 58 were used in either the development or the validation of the prediction model for the bench press exercise. The remaining 9 subjects were not used in either the development or the validation of the bench press prediction model for the following reasons:

1) One subject failed to meet the body composition inclusion criterion (body fat was greater than 35%).
2) One subject had an extremely high body weight (246 lb).
3) Seven subjects were unable to lift the required weight for the heavy bench press exercise.

The descriptive characteristics of all 58 subjects who performed the bench press exercise are presented in Table 4.1. Of the 58 subjects, 18 were randomly selected to validate the 1-RM bench press prediction model. Descriptive characteristics of those 18 subjects are presented in Table 4.2. The remaining 40 subjects were used in the development of the 1-RM bench press prediction model. Descriptive characteristics of those 40 subjects are listed in Table 4.3. The variable in bold in Table 4.3 was selected by the stepwise multiple regression analysis for inclusion in the 1-RM bench press prediction model.

Table 4.1 Descriptive Characteristics for Entire Bench Press Sample (n = 58)

VARIABLE	MEAN	+/- SD
Age (yrs)	20.28	1.79
Height (cm) Height (in.)	163.30 64.29	5.79 2.28
Weight (kg) Weight (lb)	61.12 134.47	8.76 19.28
Sum of Skinfolds (mm)	61.39	14.36
Bench press RTF* (45 lb)	12.85	6.89
Bench press RTF* (55 lb)	6.43	5.48
Bench press 1-RM (lb)	68.02	11.50

*RTF = repetitions to fatigue
1-RM = one repetition maximum
+/- SD = standard deviation

Table 4.2 Descriptive Characteristics for Bench Press Validation (n =18)

VARIABLE	MEAN	+/- SD
Age (yrs)	19.94	2.04
Height (cm) Height (in.)	164.04 64.58	4.91 1.93
Weight (kg) Weight (lb)	60.07 132.17	9.28 20.43
Sum of Skinfolds (mm)	60.52	13.80
Bench press RTF* (45 lb)	12.2	8.66
Bench press RTF* (55 lb)	6.05	6.09
Bench press 1-RM (lb)	65.83	12.27

*RTF = repetitions to fatigue
1-RM = one repetition maximum
+/- SD = standard deviation

Table 4.3 Descriptive Characteristics for Bench Press Development (n = 40)

VARIABLE	**MEAN**	**+/- SD**
Age (yrs)	20.43	1.67
Height (cm) Height (in.)	162.97 64.16	6.18 2.43
Weight (kg) Weight (lb)	61.59 135.51	8.59 18.91
Sum of Skinfolds (mm)	61.78	14.76
Bench press RTF* (45 lb)	13.12	6.03
Bench press RTF* (55 lb)	6.60	5.26
Bench press 1-RM (lb)	69.00	11.16

*RTF = repetitions to fatigue
1-RM = one repetition maximum
+/- SD = standard deviation

4.1.2 Leg Press

Of the original 67 subjects recruited, 54 were used in either the development or the validation of the 1-RM prediction model for the leg press exercise. The remaining 13 subjects were not used to either develop or validate the leg press prediction model for the following reasons:

1) One subject failed to meet the body composition inclusion criterion (body fat was greater than 35%).
2) One subject had extremely high body weight (246 lb).
3) One subject lifted an extremely high amount of weight (440 lb).
4) Ten subjects were unable to lift the required weight for the light and/or heavy leg press exercise.

The descriptive characteristics of all 54 subjects who performed the leg press exercise are presented in Table 4.4. Of the 54 subjects, 18 subjects were randomly selected to validate the 1-RM leg press prediction model. Descriptive characteristics of those 18 subjects are presented in Table 4.5. The remaining 36 subjects were used to develop the 1-RM leg press prediction model. Descriptive characteristics of those 36 subjects are listed in Table 4.6. The variables in bold in Table 4.6 were selected by the multiple regression analysis for inclusion in the 1-RM leg press prediction model.

Table 4.4 Descriptive Characteristics for Entire Leg Press Sample (n = 54)

VARIABLE	MEAN	+/- SD
Age (yrs)	20.24	1.79
Height (cm) Height (in.)	163.69 64.44	5.87 2.30
Weight (kg) Weight (lb)	61.50 135.31	9.08 19.98
Sum of Skinfolds (mm)	61.31	14.69
Leg press RTF* (175 lb)	24.37	16.10
Leg press RTF* (215 lb)	13.77	10.96
Leg press 1-RM (lb)	264.91	41.94

*RTF = repetitions to fatigue
1-RM = one repetition maximum
+/- SD = standard deviation

Table 4.5 Descriptive Characteristics for Leg Press Validation (n = 18)

VARIABLE	MEAN	+/- SD
Age (yrs)	20.50	1.75
Height (cm) Height (in.)	162.75 64.06	5.48 2.14
Weight (kg) Weight (lb)	60.55 133.22	11.40 25.08
Sum of Skinfolds (mm)	61.36	16.89
Leg press RTF* (175 lb)	21.22	14.79
Leg press RTF* (215 lb)	10.22	8.92
Leg press 1-RM (lb)	250.28	27.73

*RTF = repetitions to fatigue
1-RM = one repetition maximum
+/- SD = standard deviation

Table 4.6 Descriptive Characteristics for Leg Press Development (n = 36)

VARIABLE	MEAN	+/- SD
Age (yrs)	20.11	1.73
Height (cm) Height (in.)	164.16 64.63	6.07 2.39
Weight (kg) **Weight (lb)**	61.97 136.35	7.81 17.19
Sum of Skinfolds (mm)	61.29	13.71
Leg press RTF* (175 lb)	25.94	16.69
Leg press RTF* (215 lb)	15.55	11.56
Leg press 1-RM (lb)	272.22	46.09

*RTF = repetitions to fatigue
1-RM = one repetition maximum
+/- SD = standard deviation

4.2 CORRELATIONS AMONG VARIABLES

4.2.1 Bench Press

A stepwise multiple regression analysis was carried out to develop a 1-RM prediction model for the bench press exercise. The following predictor variables were submitted to the regression analysis: height (in.), weight (lb), sum of skinfolds (mm), and RTF at 45 lb and 55 lb. Table 4.7 presents a matrix showing correlations among the predictor variables as well as the correlation between each predictor variable and the criterion (1-RM bench press) variable for the entire bench press sample (n = 58). Table 4.8 presents the same correlation matrix for the development sub-sample (n=40). These correlations are presented for descriptive purposes only.

Table 4.7 Pearson Correlation Matrix: Predictor Variables and 1-RM Bench Press (n = 58)

	Ht (in.)	Wt (lb)	Sknfldsum	Bnchrtf 45	Bnchrtf 55	Bnch 1RM
Ht (in.)	1	0.433*	0.052	-0.113	-0.094	-0.063
Wt (lb)		1	0.676*	0.342*	0.411*	0.487*
Sknfldsum			1	0.198	0.214	0.246
Bnchrtf45				1	0.895*	0.829*
Bnchrtf55					1	0.919*
Bnch1RM						1

* Statistically significant at the $p < .05$ level (2-tailed).

Variables are:

1) Ht (in.): body height in inches
2) Wt (lb): body weight in pounds
3) Sknfldsum: sum of skinfold measurements in mm
4) Bnchrtf45: bench press repetition to fatigue with 45 pounds
5) Bnchrtf55: bench press repetition to fatigue with 55 pounds
6) Bnch1RM: bench press 1 repetition maximum

Table 4.8 Pearson Correlation Matrix: Predictor Variables and 1-RM Bench Press Development (n = 40)

	Ht (in.)	Wt (lb)	Sknfldsum	Bnchrtf 45	Bnchrtf 55	Bnch 1RM
Ht (in.)	1	0.498*	0.097	-0.124	-0.074	-0.065
Wt (lb)		1	0.639*	0.313*	0.441*	0.445*
Sknfldsum			1	0.236	0.259	0.211
Bnchrtf45				1	0.849*	0.754*
Bnchrtf55					1	0.914*
Bnch1RM						1

* Statistically significant at the $p < .05$ level (2-tailed).

Variables are:

1) Ht (in.): body height in inches
2) Wt (lb): body weight in pounds
3) Sknfldsum: sum of skinfold measurements in mm
4) Bnchrtf45: bench press repetition to fatigue with 45 pounds
5) Bnchrtf55: bench press repetition to fatigue with 55 pounds
6) Bnch1RM: bench press 1 repetition maximum

4.2.2 Leg Press

A stepwise multiple regression analysis was carried out to develop a 1-RM prediction model for the leg press exercise. The following predictor variables were submitted to the regression analysis: height (in.), weight (lb), sum of skinfolds (mm), and RTF with 175 lb and 215 lb. Table 4.9 presents a matrix showing correlations among the predictor variables as well as the correlation between each predictor variable and the criterion (1-RM leg press) variable for the entire leg press sample (n=54). Table 4.10 presents the same correlation matrix for the development sub-sample (n=36). These correlations are presented for descriptive purposes only.

Table 4.9 Pearson Correlation Matrix: Predictor Variables and 1-RM Leg Press (n = 54)

	Ht (in.)	Wt (lb)	Sknfldsum	Legrtf 175	Legrtf 215	Leg 1RM
Ht (in.)	1	0.439*	0.127	0.044	0.010	0.040
Wt (lb)		1	0.712*	0.227	0.255	0.452*
Sknfldsum			1	0.111	0.151	0.244
Legrtf175				1	0.824*	0.528*
Legrtf215					1	0.735*
Leg1RM						1

* Statistically significant at the p < .05 level (2-tailed).

Variables are:

1) Ht (in.): body height in inches

2) Wt (lb): body weight in pounds

3) Sknfldsum: sum of skinfold measurements in mm

4) Legrtf175: leg press repetition to fatigue with 175 pounds

5) Legrtf215: leg press repetition to fatigue with 215 pounds

6) Leg1RM: leg press 1 repetition maximum

Table 4.10 Pearson Correlation Matrix: Predictor Variables and 1-RM Leg Press Development (n = 36)

	Ht (in.)	Wt (lb)	Sknfldsum	Legrtf 175	Legrtf 215	Leg 1RM
Ht (in.)	1	0.434*	0.117	-0.031	-0.096	-0.024
Wt (lb)		1	0.647*	0.293	0.337*	0.463*
Sknfldsum			1	0.007	0.064	0.113
Legrtf175				1	0.862*	0.565*
Legrtf215					1	0.768*
Legrtf1RM						1

* Statistically significant at the p < .05 level (2-tailed).

Variables are:

1) Ht (in.): body height in inches

2) Wt (lb): body weight in pounds

3) Sknfldsum: sum of skinfold measurements in mm

4) Legrtf175: leg press repetition to fatigue with 175 pounds

5) Legrtf215: leg press repetition to fatigue with 215 pounds

6) Leg1RM: leg press 1 repetition maximum

4.3 1-RM BENCH PRESS PREDICTION MODEL

A summary of the stepwise regression analysis for the bench press is presented in Table 4.11. The only variable selected by the stepwise regression analysis for inclusion in the bench press prediction model was RTF with 55 lb. The regression coefficient for the model was r = 0.914. The R^2 of 0.836 indicated that 83% of the variance in the bench press 1-RM was explained by the RTF with 55 lb. The results of the ANOVA indicated that the observed value of R^2 was significantly greater than would be expected due to chance alone. Of the remaining predictor variables (height, weight, sum of skinfolds), none significantly increased the proportion of explained variance in the 1-RM bench press once RTF was in the model.

The model to predict 1-RM bench press was:

Model I: 1-RM bench press = 56.199 + 1.94(RTF55)

where RTF 55 denotes repetitions to fatigue at 55 lb.

Table 4.11 Prediction Model for 1-RM Bench Press: Summary of Multiple Regression Analysis

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	Sig. of F Change
1	0.914(a)	0.836	0.831	4.584	0.836	193.295	.000

a Predictors: (Constant), Bench press repetitions to fatigue with 55lb
b Dependent Variable: Bench press one-repetition maximum

Coefficients(a)

Mode l		Unstandardized Coefficients		Sig.
		B	Std. Error	Std. Error
1	(Constant)	56.199	1.172	.000
	Bnchrtf55	1.940	0.140	.000

a Dependent Variable: Bench press one-repetition maximum
Bnchrtf55: bench press repetition to fatigue with 55 lb

Model I was subsequently validated using a sub-sample of 18 women. For each of the 18 women in the validation sub-sample, their 1-RM bench press was predicted by inserting their RTF at 55 lb into Model I. Table 4.12 presents the measured and predicted 1-RM separately for each of the 18 subjects. A paired samples t-test indicated that the difference between the mean measured 1-RM and the mean predicted 1-RM was not significant (t (17) = -2.057, p = .055). These findings suggest that the predicted 1-RM bench press was an accurate estimate of the measured 1-RM bench press (Appendix E). The measured mean 1-RM for all 18 subjects was 65.83 lb and the predicted mean 1-RM for all 18 subjects was 67.95 lb (a difference of 2.11 lb). It is likely that the 2.11 lb difference would not be of practical significance when applying this model in a field setting (Figure 4.1). The correlation between measured and predicted 1-RM values was r = 0.935, with an R^2 of 0.875.

Table 4.12 Predicted and Measured 1-RM Bench Press

	Subject Number	Bench RTF55 lb	Predicted 1-RM (lb)	Measured 1-RM (lb)
1	2	8.00	71.72	75
2	3	1.00	58.14	55
3	10	2.00	60.08	55
4	13	1.00	58.14	55
5	19	1.00	58.14	55
6	26	8.00	71.72	70
7	33	6.00	67.84	70
8	36	2.00	60.08	60
9	43	18.00	91.12	80
10	48	7.00	69.78	75
11	49	20.00	95.00	100
12	52	3.00	62.02	60
13	54	5.00	65.90	65
14	58	1.00	58.14	55
15	61	1.00	58.14	55
16	62	15.00	85.30	75
17	64	1.00	58.14	55
18	66	9.00	73.66	70
Mean			**67.95**	**65.83**
+/- SD			**11.81**	**12.27**

Bench RTF 55lb = bench press repetitions to fatigue with 55 pounds

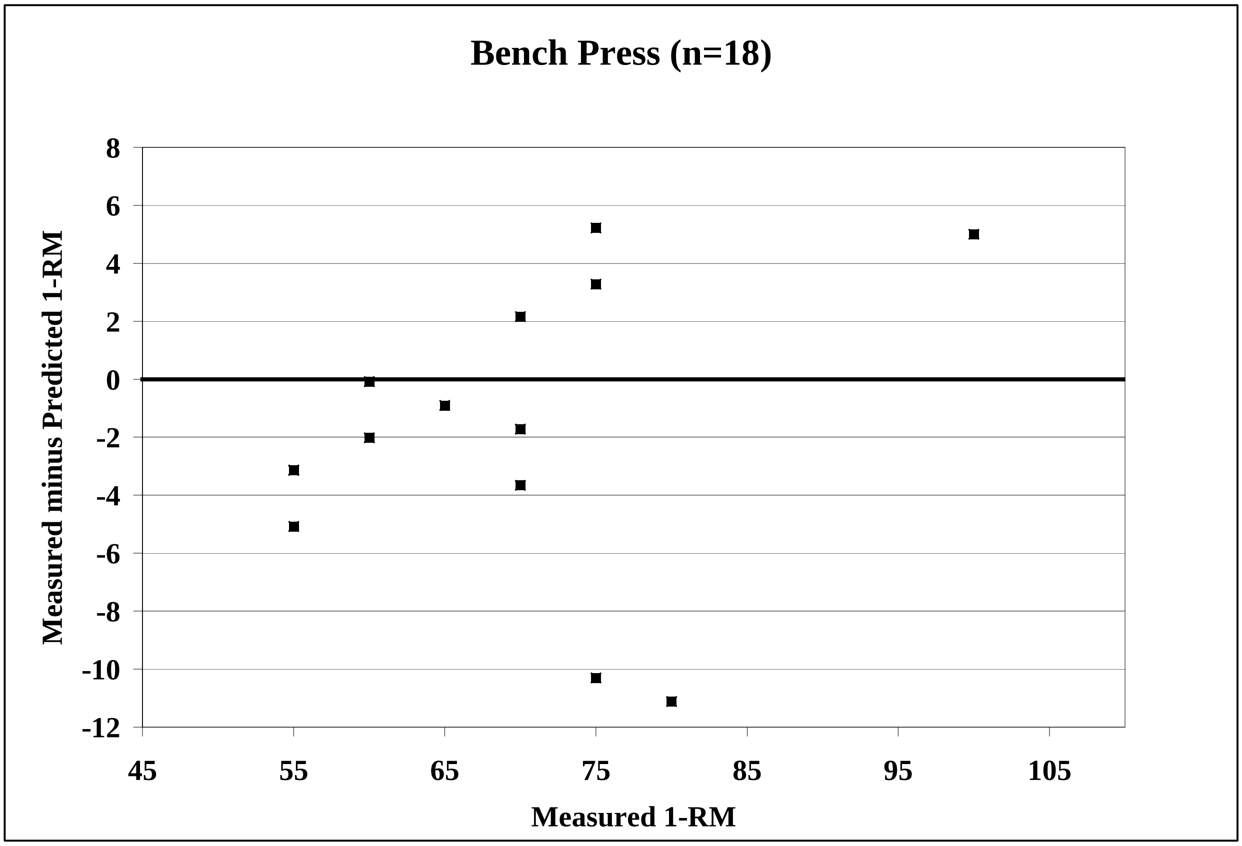

Figure 4.1 Bland-Altman Plots: Bench Press

4.4 1-RM LEG PRESS PREDICTION MODEL

A summary of the stepwise regression analysis for the leg press is presented in Table 4.13. The variables selected by the stepwise regression analysis for inclusion in the leg press prediction model were RTF with 215 lb and body weight (lb). The regression coefficient for the model was r =0 .798. The R^2 of 0.637 indicated that 64% of the variance in the leg press 1-RM was explained by the RTF with 215 lb and body weight (lb). The multiple regression selected RTF with 215 lb on the first step, and body weight (lb) on the second step (Table 4.13). The results of the ANOVA indicated that the observed value of R^2 was significantly greater than would be expected due to chance alone. Of the remaining predictor variables (height and sum of skinfolds), none significantly increased the proportion of explained variance in the 1-RM leg press once RTF and body weight were in the model.

The model to predict 1-RM leg press was:

Model II: 1-RM leg press = 145.099 + 2.752 (RTF215) + .618 (body weight)

where RTF 215 is repetitions to fatigue at 215 lb.

Table 4.13 Prediction Model for 1-RM Leg Press: Summary of Multiple Regression

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	Sig. F Change
1	0.768(a)	0.590	0.578	29.951	0.590	48.909	0.000
2	0.798(b)	0.637	0.615	28.598	0.047	4.291	0.046

a Predictors: (Constant), Leg press repetitions to fatigue with 215 lb
b Predictors: (Constant), Leg press repetitions to fatigue with 215 lb
c Dependent Variable: Leg press one-repetition maximum

Coefficients

Model		Unstandardized Coefficients		Sig.
		B	Std. Error	Std. Error
1	(Constant)	224.599	8.443	0.000
	leg215	3.062	0.438	0.000
2	(Constant)	145.099	39.215	0.001
	leg215	2.752	0.444	0.000
	Wt (lb)	0.618	0.299	0.046

a Dependent Variable: Leg press one-repetition maximum

Model II was subsequently validated using a sub-sample of 18 women. For each of the 18 women in the validation sub-sample, their 1-RM leg press was predicted by inserting their RTF with 215 lb and their body weight (lb) into Model II. Table 4.14 presents the measured and predicted 1-RM for each of the 18 subjects. A paired samples t-test indicated that the difference between the mean measured 1-RM and the mean predicted 1-RM was not significant (t (17) = -0.981, p = 0.340). These findings suggest that the predicted 1-RM was an accurate estimate of the measured 1-RM (Appendix E). The measured mean 1-RM for all 18 subjects was 250.28 lb and the predicted mean 1-RM for all 18 subjects was 255.56 lb (a difference of 5.28 lb).

It is likely that the 5.28 lb difference would not be of practical significance when applying this model in a field setting (Figure 4.2). The correlation between measured and predicted 1-RM values was 0.695, with an R^2 of 0.483.

Table 4.14 Predicted and Measured 1-RM Leg Press

	Subject Number	Leg RTF 215 lb	Body weight (lb)	Predicted 1-RM (lb)	Measured 1-RM (lb)
1	1	26.00	131	297.61	260
2	4	31.00	152	324.35	300
3	5	12.00	165	280.09	260
4	12	1.00	131	228.81	215
5	13	1.00	133	230.05	215
6	15	4.00	204	282.18	275
7	16	8.00	117	239.42	235
8	18	1.00	100	209.65	220
9	24	15.00	145	275.99	270
10	26	4.00	125	233.36	245
11	27	7.00	149	256.45	315
12	30	23.00	110	276.38	250
13	37	1.00	101	210.27	220
14	41	10.00	150	265.32	230
15	42	15.00	121	261.16	240
16	44	10.00	121	247.40	250
17	54	10.00	127	251.10	260
18	62	5.00	116	230.55	245
Mean				**255.56**	**250.28**
+/- SD				**30.46**	**27.73**

Leg RTF 215lb = leg press repetitions to fatigue with 215 pounds

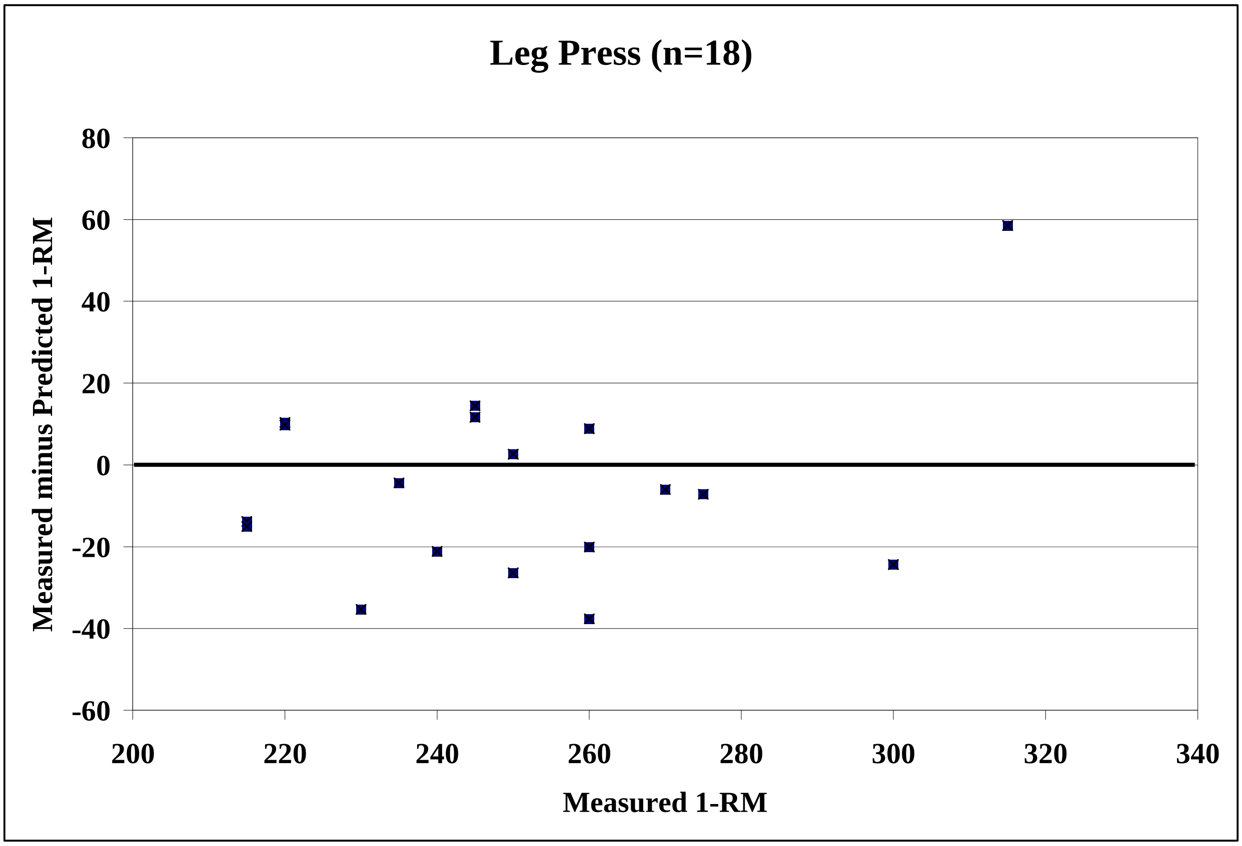

Figure 4.2 Bland-Altman Plots: Leg Press

4.5 SUMMARY OF RESULTS

In summary, Model I was developed to predict the 1-RM bench press using 40 young adult women. Model I was subsequently validated using 18 young adult women. The only variable selected by the stepwise regression analysis for inclusion in Model I was RTF at 55 lb ($r = 0.914$). The R-square indicated that 83% of the variance in the bench press 1-RM was explained by the RTF at 55 lb. Model II was developed to predict the 1-RM leg press using 36 young adult women. The model was validated using 18 young adult women. The variables selected by the stepwise regression analysis for inclusion in the leg press prediction model were RTF with 215 lb and body weight (lb) ($r = 0.798$). The R-square of 0.637 indicated that 63% of the variance in the leg press 1-RM was explained by the two predictor variables.

5.0 DISCUSSION

This investigation developed and validated prediction models to estimate upper and lower body muscular strength in non-resistance trained college aged women. The initial set of predictor variables for both upper and lower body exercises were: RTF (bench press or leg press), body height (in.), body weight (lb), and sum of skinfolds (mm). Subjects included 67 healthy, non-resistance trained women ranging in age from 18-25 years. Of the initial 67 subjects, 58 could lift both the light and the heavy weight for the bench press and were randomly assigned to either the development phase or the validation phase of the bench press model. Of the initial 67 subjects, 54 could lift both the light and heavy weight for the leg press and were randomly assigned to either the development phase or the validation phase of the leg press model. Finally, of the initial 67 subjects 51 participated in both the bench press and the leg press phases of the investigation.

A 1-RM prediction model for the bench press exercise was developed using 40 subjects. The only predictor variable that entered the bench press model (Model I) was RTF performed with 55 lb. Following development, Model I was validated using 18 subjects who were not included in the initial development phase of the experiment involving the bench press. Model I was found to be valid, having a coefficient of $r = 0.914$. A paired samples t-test indicated that the difference between the mean measured 1-RM and the mean predicted 1-RM was not significant (t (17) = -2.057, p = .055). The correlation between measured and predicted 1-RM values was r = 0.935, with an R^2 of 0.875. These findings suggest that the predicted 1-RM bench press was an accurate estimate of the measured 1-RM bench press. As such, there is no statistical and likely no practical significance in the difference of 2.11lb seen between the predicted and the measured 1-RM bench press.

The 1-RM bench press prediction model developed in this investigation is a useful assessment tool as it provides a safe and easy method to estimate the upper body strength in non-resistance trained females. In particular, no prior resistance exercise experience is required of the client or subject, very little time is needed to perform the exercise test, and the risk of injury when performing a RTF test is comparatively low. Each of these factors makes the prediction of the 1-RM bench press using Model I a more preferable method when compared to an actual 1-RM test. Furthermore, when the appropriate resistance exercise equipment (flat bench, free weight bar, and free weights) are available, the cost associated with performing this test is minimal.

A 1-RM prediction model for the leg press exercise was developed using 36 subjects. The predictor variables that entered the leg press model (Model II) were RTF performed with 215 lb and body weight (lb). Subsequently, Model II was validated using 18 subjects who were not included in the initial development phase of the experiment involving the leg press. Model II was found to be valid, having a coefficient of r = 0.798. A paired samples t-test indicated that the difference between the mean measured 1-RM and the mean predicted 1-RM was not significant (t (17) = -.981, p = 0.340). The correlation between measured and predicted 1-RM values was r = 0.695, with an R^2 of 0.483. These findings suggest that the predicted 1-RM leg press was an accurate estimate of the measured 1-RM leg press. As such, there is no statistical and likely no practical significance in the difference of 5.28lb seen between the predicted and the measured 1-RM leg press.

The 1-RM leg press prediction model developed in this investigation is a useful assessment tool as it provides a safe and easy method to estimate the lower body strength in non-resistance trained females. In particular, no prior resistance exercise experience is required of the client or subject, very little time is necessary to perform the exercise test and the risk of injury when performing a RTF test is comparatively low. Each of these factors makes the prediction of the 1-RM leg press using Model II a more preferable method when compared to an actual 1-RM test. Furthermore, when the appropriate resistance exercise equipment (leg press machine) is available, the costs associated with performing this test is minimal.

In the current investigation, a 1-RM prediction model for upper body strength (Model I) and for lower body strength (Model II) was developed for use with untrained college age females. On the first day of testing, subjects performed two bench press RTF tests using absolute weights of 45 lb and 55 lb and two leg press RTF tests using absolute weights of 175 lb and 215 lb. The selection of these absolute weights was based on a combination of pilot work, the experience of the investigator, and published research (15). The first series of tests administered on day one included performing RTF with either the light or the heavy bench press weight and performing RTF with either the light or the heavy leg press weight. The second series of tests administered on day one included performing the RTF assessment with the alternate weight (i.e. light or heavy) to that was performed during the first series of tests. The order in which the exercises were performed was randomized. Anthropometric measurements were taken on day one between the first and the second RTF tests. On the second day of testing, subjects performed a

1-RM bench press test and a 1-RM leg press test. The variable that was selected by regression analysis for inclusion in the final bench press 1-RM prediction model was RTF with 55 lb. The other variables: body height, body weight, and sum of skinfolds did not significantly explain variance in bench press 1-RM and as such were not entered into the final model. The variables that were selected by the regression analysis for inclusion in the final leg press 1-RM prediction model were RTF with 215 lb and body weight (lb). The other variables: body height and sum of skinfolds did not significantly explain variance in leg press 1-RM and as such were not entered into the final model.

An effective weight training dosage is often based on a percentage of the individual's 1-RM. Prediction models are frequently used to estimate a novice exercisers 1-RM, as they can be easier and safer than actually having the individual perform a 1-RM (2). They provide a safe guideline for the amount of weight that a woman should lift when beginning an exercise program. One of the primary predictor variables used presently in the development of the 1-RM prediction models for both the upper and lower body resistance exercises is the score derived from the RTF test (3). There is a strong, well established relation between muscular strength and muscular endurance (3). RTF tests measure muscular endurance and there is a positive relation between RTF and 1-RM (3). As such, a RTF model is often used to predict muscular strength.

5.1 1-RM BENCH PRESS PREDICTION

Through-out the investigation, upper body strength was measured using the flat bench press exercise. The flat bench press exercise is performed in a supine position, which may explain why body height and body weight were not significant predictor variables in Model I. Neither variable (height nor weight) appeared to have an impact on the maximum force that can be generated by upper body musculature when pressing the weight from a supine position. It is not clear why the sum of skinfolds did not significantly explain variance in the bench press 1-RM. It was expected that the sum of skinfolds would be related to maximum strength production while pressing a weight from a supine position. This is because the sum of skinfolds negatively correlates with lean body mass (the lower the sum of skinfolds, the higher the lean body mass) (17). A high LBM indicates comparatively more muscle mass (17), which should lead to a greater 1-RM strength measurement. The subjects in this investigation were not resistance trained and had a mean sum of skinfolds of 61.39 mm, which was equivalent to 24% body fat. This is an average percent body fat according to age and sex classification (39) and its reciprocal percent lean body mass is not indicative of large total muscle mass. Therefore, it is possible that the sum of skinfolds in the female subjects studied presently was too high (and LBM too low) to have a statistical influence in predicting the amount of weight that an individual was able to bench press. A statistically significant simple correlation was found between 1-RM bench press and the RTF score performed with 45 lb. However, this predictor variable did not enter the final model. This is because the RTF score performed with 55 lb explained comparatively more variance, making it a better predictor of the 1-RM bench press. Using the data for the initial 40 subjects in the development phase, with RTF at 55 lb as the predictor variable, the R^2 for regression Model I was 0.836 (n=40). The R^2 for the validation of regression Model I using RTF with 55 lb was 0.875 (n=18).

The experimental design of the present investigation is similar to that employed by Horvat, et al. in which 1-RM prediction models for upper body strength were developed and validated for collegiate female athletes (15). In both the present and previous investigation (15), the subjects performed a RTF bench press test using pre-determined weights. However, in the current investigation the subjects were not resistance trained. Where-as, in Horvat, et al. the subjects were resistance trained (15). The absolute weights for the RTF test in Horvat, et al. were 55 lb and 70 lb (15) versus the 45 lb and 55 lb used in the current investigation. The absolute weights selected by Horvat, et al. were based on prior research, the experience of the subjects, and pilot work (15). As with the current investigation, the subjects in Horvat, et al. (15) performed a 1-RM bench press test. In the current investigation, one regression model was developed for the bench press exercise. Horvat, et al. developed four regression models to predict 1-RM bench press (15). Three of the four models used RTF with 70 lb (15). Calculations included two split-case regression models and one overall regression model (15). There was also one overall regression model developed for repetitions performed with 55 lb (15). As with the current investigation, a RTF score at selected weights was included in the final prediction models (15). However, unlike the current investigation, LBM was included in all of the final models of Horvat, et al. (15). It is important to note that the mean percent body fat of subjects in Horvat, et al. was 18.64% (15) as compared to 24% for the subjects in the current investigation. A body fat of 18.64% suggests a comparatively high muscle mass for a female (39). Therefore, the mean LBM was higher for the women in the investigation by Horvat et.al., which may explain why LBM was included in the four 1-RM prediction models (15).

In Horvat, et al., the adjusted R^2 for the split-case regression models using a RTF with 70 lb were 0.781 (n=32) and 0.870 (n=33) (15). Rather than employing split-case regression to validate the models, as in Horvat, et al. (15), the current investigation developed a prediction model with one set of individuals (n = 40) and validated it with another set of individuals (n = 18). Horvat, et al. reported an adjusted R^2 for the overall regression model of 0.834 (n=65) where a 70 lb RTF test was used (15). This previous finding cannot be compared to those of the current investigation, as 70 lb was not a weight used in the RTF test presently employed. There were similar results between the present investigation and Horvat, et al. (15) when comparing the models that employed a RTF with 55 lb. In Horvat, et al. the adjusted R^2 for the overall regression model using a RTF with 55 lb was 0.787 (n=65)(15). Horvat, et al. did not report a split-case regression model using the 55 lb RTF test (15). In Horvat, et al. 79% of the variance in the bench press 1-RM was explained by the RTF at 55 lb (15). In the current investigation, the adjusted R^2 for Model I using RTF at 55 lb was 0.831 (n=40). As such the present findings indicate that 83% of the variance in the bench press 1-RM was explained by the RTF with 55 lb. The R^2 for the validation of Model I in the current investigation, which uses RTF with 55 lb, was 0.875 (n=18). It is of note that Horvat, et al. used resistance trained subjects to develop a 1-RM bench press model (15). The Horvat, et al. model had the same predictive power as Model I in the present investigation when a RTF with 55 lb was used. As such, Model I developed in the current investigation supports the use of a RTF test with 55 lb, providing a strong prediction of the 1-RM bench press in untrained women.

Cummings, et al. developed a new 1-RM bench press prediction model for untrained females ages 18-50 years and also compared three existing 1-RM prediction models for the bench press (8). While in the current investigation subjects performed repetitions with a predetermined absolute weight, Cummings, et al. (8) permitted each subject to perform repetitions with a self-selected weight. The goal was to identify a weight that the subject could lift between four to eight times (8). Within two days of the repetition testing, subjects also performed a 1-RM assessment and several anthropometric measurements were taken (8). The results from Cummings, et al. were used develop a new prediction model (8). The two component prediction model developed by Cummings, et al. (8) has an R^2 that is similar to the single component prediction model developed in the current investigation. The R^2 for the

Cummings, et al. two component model was 89% (8), where the R^2 for Model I in the current investigation was 84%.

Cummings et al. also tested the validity of three existing 1-RM prediction models (i.e. Brzycki, Epley, and Landers) (8). The Brzycki model (3) underestimated the measured 1-RM of the untrained 18-50 year old women who were tested in Cummings, et al. (8). It should be noted that the subjects used to develop the Brzycki model were not described in detail by either Cummings, et al. (8) or Brzycki (3). Therefore, the methodology of the Brzycki investigation (3) cannot be compared with that of the present investigation. However, the results are applicable for the prediction of 1-RM in men and women (3). The Brzycki 1-RM prediction models also appear be useful for both upper and lower body resistance exercises (3).

Landers et al. developed a mathematical equation to predict 1-RM (19). Very little methodological information was presented by Landers, et al. as there is only a prediction chart provided in the publication (19). The lowest 1-RM that can be predicted with the Landers, et al. chart is 105 lbs (19). This is a much heavier weight than the bench press 1-RM measured for the women in the current investigation. It is unclear if the Landers, et al. (19) chart is designed to be used for all exercises (upper and lower body) as well as both men and women. Therefore, values determined from this chart (19) could not be accurately compared with the bench press findings of the current investigation.

The description of the Epley 1-RM prediction model provides very little methodological information regarding its development (9). Therefore, 1-RM prediction derived from the Epley model (9) was not compared to data in the current investiation.

Many previously reported models to predict 1-RM for the upper body were developed and validated specifically for use with men (5,28,29,31-34,42,44,46,47) or with upper body exercises other than a free weight bench press (1,7,25). As such, the results from these investigations could not be compared to the results of the current investigation.

5.2 1-RM LEG PRESS PREDICTION

Body height and sum of skinfolds were not significant predictors of 1-RM leg press strength (Model II). The mechanical function of the leg press machine used to assess 1-RM leg press as well as the body position of the subject may explain why body height was not a significant predictor variable in the prediction model. The subjects began the resistance exercise in a seated position with their knees in 90° flexion. The weight was pressed straight out, not at an angle, away from their body. The position of the subject as well as the mechanical function of the leg press machine apparently negated any leverage advantage that is typically seen in those individuals who are either shorter in stature and/or who have a shorter leg length (22).

Body weight contributed significantly to explained variance in the model to predict the 1-RM leg press exercise. The heavier the individual, the more weight they were able to press. Although body weight was a significant predictor, sum of skinfolds did not significantly explain variance in the 1-RM leg press. The subjects in the present investigation were not resistance trained and had a mean sum of skinfolds of 61.31, which is equivalent to 24% body fat. This is an average percent body fat according to age and sex classification (39) and its reciprocal percent lean body mass is not indicative of a large amount of total muscle mass. Therefore, it is possible that the sum of skinfolds in the female subjects studied presently was too high (and LBM too low) to have a statistical influence in predicting the amount of weight that an individual was able to press with their legs. The total mass of the individual appeared to be a significant factor in the ability to press the weight as opposed to the proportion of tissue composition, i.e. fat and fat free mass. The emergence of body weight as a predictor variable for lower body 1-RM may also be because heavier individuals tend to have a stronger lower body. This is because a comparatively greater lean mass is required to move a greater total body mass during ambulation. Furthermore, the exercise required that the subject move the weight support arm of the leg press machine, not their body (as in a back squat). Therefore, absolute strength (not related to body weight) is more important than relative strength (related to body weight), as the subjects were not required to move their body weight (50).

Simpson, et al. suggests that body mass may be a significant predictor in determining 1-RM strength in women (41). This is particularly the case with lower body exercises, as women seem to have a greater amount of LBM in their lower than upper body (41). The explained variance in leg press 1-RM was not significantly increased by including the RTF score with 175 lb. The R^2 for the development of regression model II was 0.637 (n=36). The R^2 for the validation of Model II was 0.483 (n=18).

Much of the prior research regarding statistical models to predict lower body strength focused on developing and/or testing the accuracy of various types of squat or deadlift 1-RM prediction equations (20,48). This research focused either on the lower body strength of men (6,44), the lower body strength of women using machines (1), or older adults (38,48). Previous research has not employed a design similar to that of the present investigation in which the individual performed a RTF test with a predetermined weight and also where leg press 1-RM was directly determined.

It is difficult to compare the predictor variables from the present investigation with prior investigations, as there is very little research available on the development of models to predict lower body strength in women. A study by Simpson, et al. (41) compared the 1-RM of the upper and lower body determined with free weights to that determined with universal resistance exercise machines. The investigation developed 1-RM prediction models for both the upper and lower body separately for free weight and universal machines. The lower body exercises used in Simpson, et al. (41) were the universal leg press machine and the free weight parallel squat. Of the 124 men and women that were studied, 51 had less than one year of resistance exercise experience. Subjects performed a 1-RM assessment for the various resistance exercises but there were no RTF tests performed. Although there is very little similarity between Simpson, et al. (41) and the current investigation, it is interesting to note that body mass was a statistically significant variable in the prediction models that were developed in both of these investigations.

The leg press exercise was chosen for the present investigation because it is easy and safe to perform and it is a more practical exercise for a novice weight lifter. A prediction model was developed that can be used to estimate the 1-RM leg press by employing the RTF at 215 lb and body weight as predictor variables. Both of these predictors can be assessed quickly and accurately, making Model II a practical method for estimating 1-RM leg press strength in untrained young adult women.

The weights chosen for the leg press RTF test resulted in marked response variability between subjects. The weight was too light for some subjects, and much too heavy for others. It is possible that the ability to lift the predetermined weight was somewhat dependent on the individual's total body weight. The prediction model that was developed in this investigation includes body weight as a predictor variable indirectly supporting this hypothesis. It is possible that leg strength prediction models should be developed specific to body weight categories.

5.3 SPECIAL CONSIDERATIONS

The primary requirement when employing the upper (Model I) and lower body (Model II) prediction models developed presently is that the investigator must have the knowledge and the experience required to accurately instruct and safely “spot” a novice lifter when performing the bench press and leg press exercise.

5.4 PRACTICAL APPLICATIONS

The models developed in this investigation can be used to estimate the upper and/or lower body 1-RM strength of non-resistance trained women who are beginning an exercise program. It is not known whether the models generalize to women older than 25 years of age or with a body fat greater than 35 percent. Future research will be needed to validate a more general application of the models. It is anticipated that these equations will be useful for coaches, personal trainers, and fitness professionals who wish to design strength-training programs to enhance performance and/or health-fitness levels of the recreationally active females. There is comparatively little time and cost required to measure the variables that are used as predictors in the models developed presently. Furthermore, the subject/client needs only introductory resistance exercise skills to perform the upper and lower body RTF tests.

5.5 RECOMMENDATIONS

5.5.1 Leg length may influence the maximum weight an individual can press. As such, it is suggested that future research consider leg length measurements as a possible predictor of lower body strength when using a leg press machine.

5.5.2 The current investigation required that subjects had not performed resistance exercise for at least six months prior to participation in the study. Future research could develop 1-

RM prediction models for individuals who have had no resistance exercise experience. Individuals who have weight trained previously may have an advantage over those who have never lifted weights, as they would be more familiar with the exercises and the technique necessary to perform them.

5.5.3 The current investigation did not exclude individuals who are currently performing cardiovascular exercise. Future research should determine whether separate 1-RM prediction models are required for individuals who do perform cardiovascular exercise but do not lift weights versus those individuals who do not perform cardiovascular exercise and do not lift weights. Individuals who regularly undertake cardiovascular exercise may have an advantage when performing lower body resistance exercise because they are using and strengthening lower body muscles during each training session. These muscles would otherwise not be used if the individual was sedentary. As most cardiovascular exercises emphasize the use of lower body muscles, it would be important to determine if cardiovascular training must be accounted for in developing a model to predict lower body strength.

5.5.4 There are two important issues regarding continuation of the present line of investigation. First, future research should further corroborate the current findings for separate samples of young non-resistance trained women. Second, it is important to use the findings from this investigation to produce even more population specific prediction models. More specifically, future research should develop lower body 1-RM prediction models for non-resistance trained females that are specific to particular body weight ranges. This may help to improve the accuracy of 1-RM prediction models. The two primary suggestions are as follows:

Suggestion 1: Develop a 1-RM leg press prediction model for women who weigh less than 140 lb and for women who weigh more than 140 lb.

Suggestion 2: Develop a 1-RM prediction model for women in a specific weight range. For example, a prediction model could be developed for individuals' who weigh 100-120 lb, 120-140 lb, 140-160 lb, etc.

5.6 CONCLUSION

The participation of women in resistance training exercise programs has increased significantly in recent years. In order to develop and implement safe and effective resistance exercise programs there is a need to determine the maximal amount of weight a woman can lift, also known as a 1-RM (2). Prediction models are often used to determine a novice exercisers 1-RM. This is because such a procedure can be easier and safer than actually having the individual perform a 1-RM assessment (2) . Unfortunately, the majority of models used to predict the 1-RM for various muscle groups were either developed using males as subjects (29,31,34), or provide little information about the type of individual for whom the prediction model was intended (3,19).

The purpose of this investigation was to develop and validate 1-RM prediction models for the upper body and lower body using non-resistance trained women (18-25 years old). The upper body exercise was the bench press and the lower body exercise was the leg press.

The only variable selected by the stepwise regression analysis for inclusion in the bench press prediction model was RTF with 55 lb. The model to predict 1-RM bench press is:

Model I: 1-RM bench press = 56.199 + 1.94(RTF55)

Where: RTF 55 is repetitions to fatigue with 55 pounds.

The predicted value for each subject was found by inserting her RTF score into Model I. As an example, subject #2 from the validation sub-sample performed 8 RTF with 55 lb. The measured bench press 1-RM for subject #2 was 75 lb. Using Model I, the predicted 1-RM was determined as: Bench press = 56.199 + 1.94(8) = 56.199 + 15.52 = 71.72 lb. Therefore, subject #2 had a measured 1-RM of 75 lb and a predicted 1-RM of 71.72 lb.

The variables selected by the stepwise regression analysis for inclusion in the leg press prediction model were RTF with 215 lb and body weight (lb).

The model to predict 1-RM leg press is:

Model II: 1-RM leg press = 145.099 + 2.752 (RTF215) + .618 (body weight)

Where: RTF 215 is RTF with 215 lb and body weight (lb).

The predicted value for each subject was found by inserting her RTF score and body weight (lb) into Model II. As an example, subject #1 from the validation sub-sample completed 26 RTF with 215 lb and had a body weight of 131 lb. The measured leg press 1-RM for subject #1 was 260 lb. Using Model II the predicted 1-RM was determined as: Leg press = 145.099 + 2.752 (26) + .618 (131) = 297.61). Therefore, subject #1 had a measured 1-RM of 260 lb and a predicted 1-RM of 297.61 lb.

The models developed in this investigation can be used to estimate the upper and/or lower body 1-RM strength of young non-resistance trained women who are beginning an exercise program. These models will be useful for coaches, personal trainers, and fitness professionals who wish to design strength-training programs and to enhance performance and the health-fitness levels of recreationally active females.

APPENDIX A

PHYSICAL ACTIVITY READINESS QUESTIONNAIRE (PAR-Q)

Date ___________

ID#____________

Now I am going to ask you a few questions to determine if you are eligible to complete the resistance exercise…

1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?

   No_____ Yes_____ If Yes, specify________________________________

2. Do you feel pain in your chest when you do physical activity?

   No_____ Yes_____ If Yes, specify________________________________

3. In the past month, have you had chest pain when you were not doing physical activity?

   No_____ Yes_____ If Yes, specify________________________________

4. Do you lose your balance because of dizziness or do you ever lose consciousness?

   No_____ Yes_____ If Yes, specify________________________________

5. Do you have a bone of joint problem that could be made worse by a change in your physical activity?

   No_____ Yes_____ If Yes, specify________________________________

APPENDIX A (CONTINUED)

6. Is your doctor currently prescribing drugs (for example, water pills) for a blood pressure or heart condition?

   No_____ Yes_____ If Yes, specify______________________________

7. Do you know of any other reason why you should not do physical activity?

   No_____ Yes_____ If Yes, specify______________________________

APPENDIX B

INFORMED CONSENT DOCUMENT

University of Pittsburgh
Institutional Review Board
Approval Date: 12/20/06
Renewal Date: 8/28/07
IRB Number: 0607065

CONSENT TO ACT AS A PARTICIPANT IN A RESEARCH STUDY

TITLE: Development of prediction equations to estimate the 1-RM for upper and lower body exercises in non-resistance trained women

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SOURCE OF SUPPORT: University of Pittsburgh School of Education Grant

Participant's Initials_______

University of Pittsburgh
Institutional Review Board
Approval Date: 12/20/06
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IRB Number: 0607065

Why is this research being done?

The participation of women in athletics and/or regular physical exercise programs has increased significantly. Among the many physical activities that women engage in is weight lifting. Some of the reasons that women lift weights are to increase their strength for other activities (such as hiking, swimming, dancing), to prevent bone loss (osteoporosis), or to just improve their health and/or physical appearance. In order to design and use a weight training program, it is important to know how much weight a woman can lift one time, also known as a 1 repetition maximum (1-RM). Often, prediction equations (a statistically determined equation) are used to determine a new exerciser's 1-RM, because these equations can be easier and safer than actually having the individual lift as much weight as they possibly can at one time (1-RM). Usually, the upper body exercise used in these predictions is the bench press and the lower body exercise is the leg press. The purpose of the present research study is to develop a one-repetition maximum prediction equation for the upper and lower body specifically for non-resistance trained females.

Who is being asked to take part in this research study?

You are being invited to take part in this research study because you are a healthy female between the ages of 18-25 years who is not currently participating in a weight training program. You will not be eligible for this study if you are an inter-collegiate athlete, have a body fat percentage greater than 35% (this will be determined at the beginning of the study), and/or pregnant. In addition, if you have bone, joint, heart, muscular, and/or metabolic disorders (ie: diabetes) you will not be eligible for this study.

What procedures will be performed for research purposes?

If you decide to participate in this study, you will complete 2 testing sessions. Session one includes an orientation and an exercise session and session two includes an exercise session. Each session is separated by a minimum of 2-3 days and a maximum of 5 days. All testing will be performed in the Peterson Fitness Center at the University of Pittsburgh. Session 1 will take approximately 1 1/2 hours and is as follows:

Participant's Initials_______

1. Completion of the informed consent and a health questionnaire called the PAR-Q (Physical Activity Readiness Questionnaire) (5 minutes)
2. Urine pregnancy test (5 minutes)
3. Measurement of your body height and weight using a standard physician's scale. (1 minute)
4. Measurement of your body's muscle mass and fat using a Lange skinfold caliper. (5 minutes) The skinfold caliper is a pain free hand held instrument that will be used to measure your body fat.
5. Weight lifting exercise orientation and technique. The primary investigator will show you how to perform the bench press and the leg press exercises that will be performed. (30 minutes)
6. General warm up procedures will be reviewed by the investigator in detail. This will include riding a bicycle, performing 15 jumping jacks and stretches. (15 minutes)
7. Bench press 45 pounds and bench press 55 pounds as many times as you can (until you get tired). Leg press 175 pounds and leg press 215 pounds as many times as you can (until you get tired). The weight that you lift the first time and the weight that you lift the second time will be determined by a coin toss. If you lift the lighter bench press first, then you will lift the heavier bench press second. If you lift the heavier leg press first, then you will lift the lighter leg press second. It will take approximately 1 minute to complete both the bench press and the leg press exercise. After you perform the bench press and the leg press exercise for the first time, you will have a 15 minute rest before you perform the bench press and the leg press for the second time. During the 15 minute rest, the skinfold measurements (described in number 4) will be taken. If you cannot lift any of the above weights, you will still get paid for participating in the study. (20 minutes. The 20 minutes includes the 5 minutes discussed in # 4 above.)
8. There will be a minimum of 2-3 days and a maximum of 5 days separating both sessions.

Session 2 will take approximately 1 hour and is as follows:

1. General warm-up as demonstrated during session 1.

Participant's Initials______

2. 1-RM determination for both the bench press and the leg press exercises (30 minutes for each exercise). The 1-RM is the most amount of weight that you can lift one time. With the exception of the beginning weight, the principle investigator will be responsible for determining the weight that you will attempt to lift, but you may refuse to lift any weight for any reason. To determine your bench press 1-RM, you will begin by lifting 45 pounds between 5-10 times. After a 1 minute rest, you will lift a slightly heavier weight between 3-5 times. After resting for 2 minutes, you will try to lift a slightly heavier weight for 2-3 times. You will rest for another 2-4 minutes, then try to lift a slightly heavier weight again. You will continue to lift a heavier weight until you can only lift the weight one time. It should take approximately 5 attempts to reach your 1-RM, but it may take fewer or more attempts (you may reach your 1-RM after 1 attempt, or it may take 6-7 attempts). The same format will be followed for the leg press (however, you will start with 175 pounds).

What are the possible risks, side effects and discomforts of this research study?

Risks of the resistance exercise tests

The most likely side effect and discomfort encountered during both the bench press exercise and leg press exercise is muscular soreness that could last for 2 days. Muscular fatigue and soreness is common (expected to occur > 10% of people: 10-25 out of 100) following both sessions. This fatigue and soreness can appear up to 24 hours after the exercise has been performed and should not last more than two days. The fatigue and soreness should not inhibit any of your regular daily activities. Muscular sprains and strains are rare (< 1% of people). The greatest risk associated with performing these exercises is the use of improper form. These risks will be minimized by the detailed instruction provided to each subject during the orientation and all sessions following. To minimize the risks associated with the testing, you will also complete the Physical Activity Readiness Questionnaire, which will ask questions about your current health status.

Participant's Initials______

University of Pittsburgh
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What are the possible benefits from taking part in this study?

You will receive no direct benefit from taking part in this research study. However, you will learn the safest way to perform both the bench press and leg press resistance exercises. You will learn what your current 1-RM bench press and leg press is. You will learn what your percent body fat is. All of this information helps you to better understand your current fitness status.

If I agree to take part in this research study, will I be told of any new risks that may be found during the course of the study?

You will be promptly notified if, during the conduct of this research study, any new information develops which may cause you to change your mind about continuing to participate.

Will my insurance provider or I be charged for the costs of any procedures performed as part of this research study?

Neither you, nor your insurance provider, will be charged for the costs of any procedures performed for the purpose of this research study.

Will I be paid if I take part in this research study?

You will be paid $20.00 for completing all parts of this research study. You will be paid even if you cannot lift one or all of the weights in the two sessions.

Who will pay if I am injured as a result of taking part in this study?

University of Pittsburgh researchers and their associates who provide services at UPMC recognize the importance of your voluntary participation in their research studies. These individuals and their staff will make reasonable efforts to minimize, control, and treat any injuries that may arise as a result of this research. If you believe that you are injured as a result of the research procedures being performed, please contact immediately the Principal Investigator or one of the Co-investigators listed on the first page of this form.

Participant’s Initials______

Emergency medical treatment for injuries solely and directly related to your participation in this research study will be provided to you by the hospitals of UPMC. It is possible that the UPMC may bill your insurance provider for the costs of this emergency treatment, but none of these costs will be charged directly to you. If your research-related injury requires medical care beyond this emergency treatment, you will be
responsible for the cost of this follow-up unless otherwise specifically stated below. There is no plan for monetary compensation. You do not; however, waive any legal rights by signing this form.

Who will know about my participation in this research study?
Any information about you obtained from this research will be kept as confidential (private) as possible. All data will be in control of the principal investigator. The principal investigator will be the only individual to have access to all research data.
All records related to your involvement in this research study will be stored in a locked file cabinet. Your identity on these records will be indicated by a case number rather than by your name, and the information linking these case numbers with your identity will be kept separate from the research records. You will not be identified by name in any publication of the research unless you sign a separate consent from giving your permission (release).

Will this research study involve the use or disclosure of my identifiable medical information?
This research study will not involve the use or disclosure of any identifiable medical information.

Who will have access to identifiable information related to my participation in this research study?
In addition to the investigators listed on the first page of this authorization (consent) form and their research staff, the following individuals will or may have access to identifiable information related to your participation in this research study.

- Authorized representatives of the University of Pittsburgh Research Conduct and Compliance Office may review your identifiable research information for the purpose of monitoring the appropriate conduct of this research study.

Participant's Initials______

- In unusual cases, the investigators may be required to release identifiable information related to your participation in this research study in response to an order from a court of law. If the investigators learn that you or someone with

  whom you are involved is in serious danger or potential harm, they will need to inform, as required by Pennsylvania law, the appropriate agencies.
- Authorized people sponsoring this research study, because they need to make sure that the information collected is correct, accurate, and complete, and to determine the results of this research study.

- Authorized representatives of the UPMC hospitals or other affiliated health care providers may have access to identifiable information related to your participation in this research study for the purpose of (1) fulfilling orders, made by the investigators, for hospital and health care services (e.g., laboratory tests, diagnostic procedures) associated with research study participation; (2) addressing correct payment for tests and procedures ordered by the investigators; and/or (3) for internal hospital operation (i.e. quality assurance).

For how long will the investigators be permitted to use and disclose identifiable information related to my participation in this research study?

The investigators may continue to use and disclose, for the purposes described above, identifiable information related to your participation in this research study for a minimum of five years after final reporting of publication of a project.

Is my participation in this research study voluntary?
Your participation in this research study, to include the use and disclosure of your identifiable information for the purposes described above, is completely voluntary. (Note, however, that if you do not provide your consent for the use and disclosure of your identifiable information for the purposes described above, you will not be allowed, in general, to participate in the research study.) Whether or not you provide your consent for participation in this research study will have no effect on your current or future medical care at UPMC hospital or affiliated health care provider or your current or future relationship with a health care insurance provider.

Participant's Initials______

May I withdraw, at a future date, my consent for participation in this research study?

You may withdraw, at any time, your consent for participation in this research study, to include the use and disclosure of your identifiable information for the purposes described above. Any identifiable research information recorded for, or resulting from, your participation in this research study prior to the date that you formally withdrew your consent may continue to be used and disclosed by the investigators for the purposes described above.

To formally withdraw your consent for participation in this research study you should provide a written and dated notice of this decision to the principal investigator of this research study at the address listed on the first page of this form.

Your decision to withdraw your consent for participation in this research study will have no effect on your current or future relationship with the University of Pittsburgh. Your decision to withdraw your consent for participation in this research study will have no effect on your current or future medical care at a UPMC hospital or affiliated health care provider or your current or future relationship with a health care insurance provider.

If I agree to take part in this research study, can I be removed from the study without my consent?

It is possible that you may be removed from the research study by the researchers to protect your safety or you are unable or unwilling to complete the research protocol.

Participant's Initials______

VOLUNTARY CONSENT:
All of the above has been explained to me and all of my current questions have been answered. I understand that I am encouraged to ask questions about any aspect of this research study during the course of this study, and that such future questions will be answered by the researchers listed on the first page of this form.

Any questions which I have about my rights as a research participant will be answered by the Human Subject Protection Advocate of the IRB Office, University of Pittsburgh (1-866-212-2668).

By signing this form, I agree to participate in this research study. A copy of this consent form will be given to me.

_______________________________________ ________________

Participant's Signature Date

CERTIFICATION OF INFORMED CONSENT

I certify that I have explained the nature and purpose of this research study to the above-named individual(s), and I have discussed the potential benefits and possible risks of study participation. Any questions that the individual(s) has about this study have been answered, and we will always be available to address future questions as they arise. I further certify that no research component of this protocol was begun until after this consent form was signed.

Carol L Brennan Primary Investigator

Printed Name of Person Obtaining Consent Role in Research study

_______________________________________ ________________

Signature of Person Obtaining Consent Date

APPENDIX C

BENCH PRESS

APPENDIX D

LEG PRESS

APPENDIX E

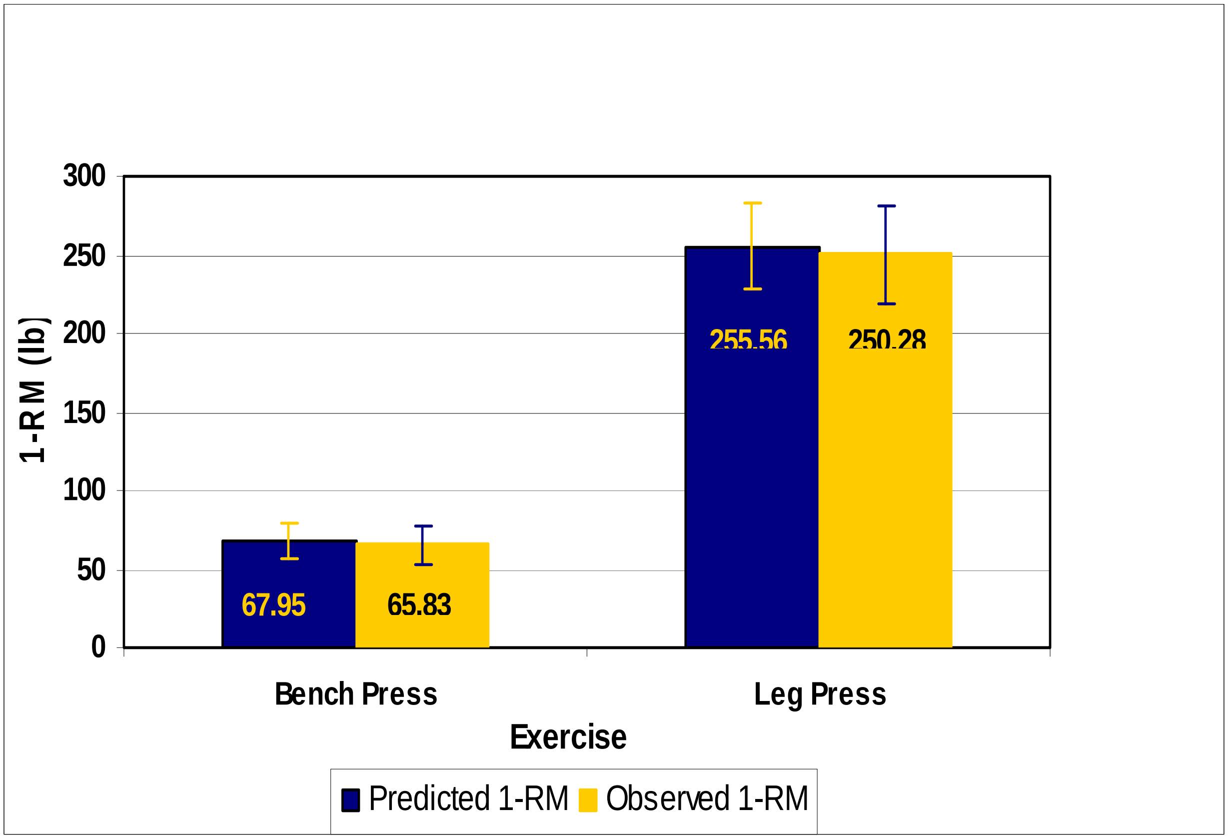

Figure A.1 Mean Predicted vs Mean Measured 1-RM

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