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Validation of the Brzycki and Epley Equations for the 1 Repetition Maximum Back Squat Test in Division I College Football Players

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by

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Approved by:

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Introduction

Strength training has become a staple of athletic preparation in the collegiate setting of Division I athletics. Year round preparation has emerged as a necessity to allow athletes reach the heights of their physical potential. Resistance training allows for significant gains in muscular strength (Fleck & Kraemer, 1997). In order to examine strength, it first must be defined. Baechle & Wathen (1994) defined strength as the force that a muscle or muscle group can exert against resistance. Rippetoe (2011) uses the tangible, measurable definition of muscular strength as the physical ability to generate force against an external load (Rippetoe, 2011). To measure the amount of force that a muscle can exert against an external resistance, a specific test, the one repetition maximum (1RM) is most commonly used assessment (Arthur, 1982; LeSuer & McCormick, 1997). The 1RM is, in and of itself, a test of the ability of the system to move an external load through a full range of motion to the extent of the system's capabilities. As such, it can be seen that this commonly used 1RM test is the most accurate method of assessing muscular strength (Mayhew et al., 1995).

Despite the fact that the 1RM is the most accurate measure of muscular strength, there are perceived safety concerns, time constraints, and systemic stresses induced from such an effort (Madsen & McLaughlin, 1984; Mayhew et al., 1992). Attempting a 1RM requires a great deal of focus and mental preparation on the lifter's behalf. With this, a maximal exertion for a single repetition consumes a large amount of training time and an excessive amount of the trainee's recuperative resources. Simply put, the time and energy spent in performing a 1RM detracts from the training regime, and can be a strenuous event to recover from. In light of this, many practitioners and coaches view the 1RM as dangerous and impractical in most exercise settings.

Many strength and conditioning coaches utilize submaximal testing to estimate the 1RM for a variety of strength measures.

A procedure of testing and training that uses less than a 1RM load (a maximal effort) offers several appeals. First off, training with 1RM loads frequently is risky and detracts from the training process. Submaximal efforts are beneficial for the acquisition of strength/ power, and allow for an estimate of the trainee's progress/strength limits. If additional repetitions can be performed at the same load, or the same amount of repetitions can be performed at a heavier load, it is intuitively obvious that the trainee has become stronger to some quantifiable extent. With this, the performance of such submaximal sets allow for the safe and effective development of strength that can be systematically increased towards a desired goal of becoming stronger (this is the process of training). The combination of the training effect elicited through the use of submaximal sets along with the ability to use data from these submaximal performances as indicators of 1RM/absolute strength of the trainee makes the submaximal set a salient tool for the strength and conditioning coach. Accurate prediction equations for the 1RM, based on submaximal efforts, are therefore of great deal to the strength and conditioning professional.

Many strength and conditioning coaches utilize percentage-based programs to develop their strength training regimens (Pauletto, 1991). Most exercises are performed at a designated percentage of the athlete's strength capabilities (1RM). As such, assigning an accurate 1RM plays a large role in the designing and implementing of a strength-training program. If the 1RM is overestimated by a prediction equation, the weights used for training will be too heavy for the respective athlete, leading to increased risk of injury and overtraining, along with expedited stagnation. On the other side of the coin, if the predicted 1RM is underestimated the athlete will be training with lighter weights than what would allow for optimal gains in strength and lead to delayed training benefits and possible lack of enough training stimulus needed to force adaptation. Understanding the importance of an accurate 1RM, it can be seen that prediction equations based on submaximal efforts are of value to the strength and conditioning coach and strength practitioners in general. As mentioned earlier, testing a true 1RM in an exercise carries a risk of injury, takes a lot of time, and places a large amount of stress on the athlete. Despite this, strength and conditioning coaches benefit from an accurate assessment of an athlete's 1RM for program design purposes. In lieu of a 1RM test, submaximal testing can be utilized, and with valid prediction equations, an accurate 1RM can be predicted based on these lower risk tests of strength.

It should also be noted that throughout the process of strength training, an athlete's 1RM is constantly changing. Through resistance training, and the adaptive ability of the human body, acquisition of strength is continuous. The trainee is subjected to a stress and, in the absence of under-stressing/overstressing the system, the trainee adapts and gets stronger. This creates a situation in which the athlete's ability to produce force against an external load (i.e. strength capability) increases at an ever-changing rate. This is the goal of strength training; to get stronger. Being able to accurately predict a trainee's 1RM from a submaximal test is of great value to a strength and conditioning professional due to the fact that submaximal tests can not only be used as a training tool, but also as an assessment of the trainee's strength. Submaximal tests to fatigue are a powerful training stimulus that allow for adaptation, but are not so taxing that the trainee cannot recover from such efforts in a short period of time (as seen with a 1RM test). Coinciding with this training effect, these submaximal tests can provide insight into the trainee's current 1RM without actually testing his or her 1RM at that time. This is another reason why valid prediction equations are of use to strength and conditioning professionals throughout the training year.

Currently there are several prediction equations for estimating the absolute strength of a resistance-trained subject, based on submaximal efforts to fatigue. Investigators have performed numerous studies evaluating different submaximal percentages of maximal strength (Brzycki, 1993; Hoeger et al., 1990; Landers, 1985; Mayhew et al., 1992; Mayhew et al. 1992; Mayhew et al., 1995; Mayhew et al., 1993). The findings from these studies have led to the development of several formulas to estimate 1RM from repetitions to fatigue. At the root of these formulas is the strong association between a trainee's strength capabilities (1RM) and the number of repetitions to fatigue with a submaximal weight (LeSueur et al. 1997). Despite this association, when more than 10 repetitions are performed in a submaximal test, there appears to be a greater difference between the actual 1RM and the predicted 1RM (Chapman et al., 1998; Ware et al., 1995; Whisenant et al., 2003).

Two commonly used prediction equations in the strength and conditioning profession are the Brzycki (Brzycki, 1993) and the Epley (Epley, 1985) equations (Butt, 2001). These equations are widely employed mostly due to their ease of use and widespread history of application. Many coaches are familiar with the Brzycki and Epley equations, and as such these two equations had been adopted as commonplace predictors of 1RM in the strength and conditioning profession. Similar to other 1RM prediction formulas derived from submaximal tests to fatigue, the Brzycki and Epley equations yield more accurate 1RM estimates when the number of repetitions performed in these types of submaximal test is less than ten (Ware et al., 1995; Whisenant et al., 2003). Understanding the widespread use of these two equations, it is valuable to look that the validity of these prediction equations when applied to collegiate football athletes for the back squat exercise. Training athletes for power related sports such as football is comprised largely of submaximal efforts in weight training exercises that involve multi-joint, compound movements. Very often the majority of work done in this setting is with a repetition range of 1-5. Training with repetitions of 1-5 yields the greatest increases in strength and power, and as such are staples in any football strength and conditioning program (Kraemer, 1997). Understanding this, and knowing that the validity of the Brzycki and Epley equations increases with decreasing repetitions, it is valuable to look at these prediction equations as how they apply to submaximal tests to fatigue at 5 repetitions or less.

In the collegiate football setting, the most common training tool for the development and measurement of lower body strength is the back squat (Arthur, 1982). This weight room exercise is one of the most effective drivers of athletic ability due to the inherit nature of the exercise. The back squat is the only exercise of weighted human movement that allows the direct training of the complex movement pattern known as hip drive. The posterior chain is a term that refers to the muscles that produce hip extension: straightening out of the hip joint from its flexed position in the bottom of the squat. The muscles that accomplish hip extension are the hamstrings, the gluteal muscles, and the adductors of the legs. Together this group of muscles is referred to as the posterior chain. The initial movement up out of the bottom of a full squat is hip drive, and is best thought of as a shoving-up of the sacral area of the lower back out of the bottom of the squat position.

This hip drive is essential to the development of athletes because it involves the recruitment of the entire posterior chain. The back squat is a mode to train hip drive in a way that is progressively improvable, and as such it is the best barbell exercise available to enhance athletic performance. These posterior chain muscles used in the back squat also contribute to jumping, pulling, pushing, and any athletic motion involved with football. The back squat trains the posterior chain more effectively than any other movement. No other movement involves enough range of motion to use all of the posterior chain musculature, and no other exercise works this long range of motion by preceding muscular contraction with an eccentric lowering, which produces a stretch-shortening cycle or stretch reflex. The stretch reflex produces a much harder contraction than would be possible without it, one that recruits many more motor units than would be available without the loaded pre-stretch provided by the lowering phase of the lift.

Despite the fact that the back squat is one of the best tools strength and conditioning coaches have in their weight room, there is not much in the scientific literature assessing the relationship between submaximal testing of the back squat and how these tests predict a back squat 1RM. Effective prediction formulas for the 1RM back squat will be able to accurately predict the 1RM of a trainee based on his submaximal efforts. The Brzycki and Epley formulas have been used in weight rooms throughout the United States of America for close to 20 years now. Evaluating their effectiveness as prediction formulas would allow for coaches and players to confidently regard these equations as accurate or disregard their efficacy with relation to the back squat. If effective, then accurate predictions of strength can be determined based on submaximal tests, thus saving valuable training time, recuperative resources, and ultimately reduce the risk of injury in the weight room.

Statement of Purpose

The purpose of this study is to evaluate the validity of the Brzycki and the Epley equations to estimate the 1RM back squat, based on submaximal efforts of three repetition maximum (3RM) and five repetition maximum (5RM) tests with Division I college football athletes.

Hypothesis

Within this study, the hypothesis tested was based on two areas of investigation from which an accurate 1RM can be determined from submaximal efforts. The first area of investigation delved into the loads with which 1RMs can be derived from using prediction equations. The effectiveness of submaximal efforts for predicting 1RM may be limited when higher repetitions with lighter weights are used in the squat for highly trained athletes (Ware et al., 1995). With this, fewer repetitions (<10) with heavier loads (>80% 1RM) may be more accurate than higher repetitions with lighter loads for estimating 1RM in the squat for resistance trained athletes (Ware et al., 1995). Overall it is suggested that repetitions with loads closer to the 1RM of the subject offer better capability for predicting maximal strength (Stone & O'Bryant, 1987). Understanding this, the first portion of the hypothesis tested in this study was that submaximal back squat tests using 3RM loads more accurately predict 1RM strength than submaximal back squat tests using 5RM loads. Branching off of this, two equations: the Brzycki (1993) and Epley (1985) equations, were brought into review for the back squat exercise as they relate to 3RM and 5RM tests being reliable predictors of 1RM strength. The Brzycki and Epley formulas are both linear, but previous studies have found to the Epley equation to be more accurate in predicting 1RM than the Brzycki equation (Ware et al., 1995; Whisenant et al., 2003). Noting this, the second portion of the hypothesis tested in this study was that the Epley equation is more accurate in predicting 1RM capabilities of a participant than the Brzycki equation. Overall, the research hypothesis examined in this study was that the Epley equation is more accurate than the Brzycki equation in predicting 1RM capabilities, and that when using these equations; the 3RM back squat load is more accurate than the 5RM back squat load for predicting a participant's 1RM.

Definition of Terms

The following operational definitions are described as to their use in the performed study. Strength is the primary attribute being studied and it must be defined in order to understand the framework in which this study operates. Strength is defined the physical ability to generate force against an external load (Rippetoe, 2011). An accurate test must be used to assess a participant's strength capabilities in order to measure this ability to generate force. The gold standard test of strength is the 1RM (Mayhew et al., 1995), and as such the 1RM are defined as the participant's true measure of strength within this study.

Along with the 1RM, 3RM and 5RM lifts were used as submaximal measures of strength as well. A 3RM lift is defined as the most amount of weight that the participant could squat for three successful repetitions (all of which meet the criteria for a correct squat). A 5RM lift is defined as the most amount of weight that the participant could squat for five successful repetitions (all of which meet the criteria for a correct squat). From these submaximal efforts, two prediction equations were used to calculate a predicted 1RM. A predicted 1RM is defined as the estimated strength capability of a participant, based on his performance in a submaximal squat test. For this study, the submaximal squat tests being used were the 5RM and the 3RM, and the two formulas used to predict the 1RM were the Brzycki (1993) and the Epley (1985) equations.

Assumptions

In testing the participants, some basic assumptions of training background were made based on the athletes being selected for the study. Since the participants being studied were selected from a Division I college football program that incorporates the back squat, the athletes performing the 5RM, 3RM, and 1RM tests were assumed to have a familiarity with the exercise.

The tested athletes used the back squat in their prior training as part of the 9 week resistance training program, so the assumption at the time of testing was that the athletes were proficient in the back squat exercise. With this, the athletes being tested were instructed to perform each test with maximal effort. It was assumed that the participants used in the study were putting forth maximal effort in each of the back squat tests.

With respect to the participant's readiness to exert a maximal effort, assumptions were made about their physical preparedness, nutritional status, and arousal levels. The 5RM, 3RM, and 1RM back squat tests were all performed in a controlled environment, at the same time of the day, and using the same equipment. The testing procedures were standardized, and although the previous training days earlier in the week were variable in intensities, the exercises and volume were held constant. That being said, it was assumed that the nutritional status of each trainee was similar to the testing sessions for each maximal effort. With this it was also assumed that the participant was well rested prior to each testing session, and that he had not done any workouts other than the designated resistance training program prior to testing. Understanding the variability of the college football athlete's daily schedule and diet, it is somewhat presumptuous to assume that all the participants were equally prepared before each testing session. Despite this bold assertation, these are the confines of the collegiate system that takes place in real life training of athletes. There are confounding variables inherent to the outside life of the athlete that affects his or her performance in the weight room. It is impossible to control for all of these variables of daily living for each athlete. The most prudent method to allow for consistent testing is to control for the variables within the testing session itself and encourage athletes to eat a consistent diet, not do any outside workouts other than the prescribed lifting protocol, and to come into the testing sessions ready to give their maximal effort.

Delimitations

The following conditions provide the parameters under which the research was conducted. In order to eliminate the differences seen between male and female, only males were used in the study. With hopes to limit the differences in squat technique among participants, athletes with similar training backgrounds (taken from the same Division I college football program) and congruent coaching (the same strength and conditioning coaches taught all participants how to perform the back squat throughout the 9 week training session) will be studied. The same training methodology and resistance training programs were used for all the participants with the strength and conditioning coaches controlling the load assignments throughout the 9 weeks. This was done in effort to control the training background of each participant, such that each participant's prior training to the testing sessions was as consistent as possible. The same testing procedures were followed for all back squat tests. A single experimenter conducted all data collection and the same strength and conditioning coaches were used to supervise each back squat test.

Limitations

By concentrating the study participants to male, Division I college football players, the scope of the study is reduced. The application of the findings will not be as universally applicable as would be seen in including females, untrained individuals, etc. With this, the participants included in this study were not screened for demographics. Demographic variables play a role in the validity of 1RM prediction equations (Whisenant et al., 2003) and can influence the accuracy of the formulas used. Another limitation of the study is inherent to the training of collegiate athletes. College strength and conditioning is a business in which the athletes are pushed to perform to the upper levels of their capabilities and driven to succeed. The athletes are internally as well as externally motivated to work towards the goal of getting stronger and moving more weight. There are multitudes of confounding variables that affect the participants in their performance on the tested 1RM, 3RM, and 5RM; and although an effort to control for these variables was sought, to think that they were all limited would be impudent. Encouragement, training environment, nutritional status, arousal levels of each athlete, to name a few, are all factors that are not able to be controlled for in the collegiate weight room. Gathering data in this setting is secondary to the performance of the athletes. The strength and conditioning coaches seek to enhance the performance to their athletes, and the athletes seek to enhance their own performance as well. Researchers can work to limit the differences between the testing sessions and control for as many variables that will grossly affect the outcome of the study, but realistically there is going to be inherent variables that cannot be controlled for within the study.

In line with this, it should be noted that the 5RM, 3RM, and 1RM were all tested on the same day of the week, at the same time of the day, on the same equipment. The training sessions earlier in the week leading up to the testing sessions were the same exercises, sets, and reps, but the loads for these sessions were different than the week prior. Simply put, Monday's and Wednesday's training leading up to the 5RM test on Friday were lighter than the Monday and Wednesday training leading up to the 3RM, which was lighter than the training sessions leading up to the 1RM. This is again due to the fact that the athletes used as participants are training to enhance performance and they are working to get stronger on a weekly basis. With the increasing load, there may have been residual fatigue that could have affected performance on the 5RM, 3RM, and 1RM tests. There also may have been training adaptation that took place as a result of prior training and thus increasing the performance of the 5RM, 3RM, and 1RM tests over what was capable in the weeks past. Strength training leads to fatigue, from which the body adapts and compensates for by becoming stronger. This is the process from which resistance training elicits strength gains. There is a balance between this fatigue and the ability of the body to recover, which is highly individual to the trainee based on his/her training status, age, gender, nutritional status, etc. (Rippetoe & Baker, 2014). Accounting for where the trainee is within the weekly training cycle can be assessed through maximal tests such as a 5RM, 3RM, and 1RM. Due to the fact that these tests were used for data for this study, there was limited availability to account for where the participants fatigue levels were at during the time of the test. He may have been less fatigued for the 5RM than he was the 1RM, but this was not something that could be accounted for. It is unrealistic to measure the levels of fatigue/adaptation for a trainee at any given time, unless an assessment is taken. In this study, the assessment was the 5RM, 3RM, and 1RM and these were the final data points used. This is intrinsic to the process of training; there is no way around this. Training elicits an adaptation after a period of fatigue. The trainee's ability to respond to training is demonstrated through maximal tests. These tests are assessments as well as stresses that force adaptation within the human system, and as such the trainee is different (stronger or more fatigued) from one assessment to another. No matter how many variables are accounted for, a participant will never have the exact same strength capabilities from one strength test to another.

Significance of Study

The back squat is one of the most liberally used lower body strength exercises in resistance training programs for college football players. Not only is the back squat an effective tool for total body strength and power development, it is also the primary exercise used to evaluate the strength level of college football players (Arthur, 1982). Although the 1RM is the most accurate and truest test of strength, attempting such a lift requires a great deal of time and resources on both the coach's and athlete's behalf. Submaximal tests are safer and easier to implement, and also have a strong training effect that leads to strength development as a result of the effort (Rippetoe, 2011). Being able to accurately predict a 1RM from a submaximal effort offers the athlete and coach tangible evidence of progress during a regular training workout. This evidence not only allows the trainee to see real-time improvement, it allows the coach to make better judgments on training and planning for the future. Strength acquisition is an adaptive process that does not remain stagnant and then take a marked jump upwards or downwards at the time of a 1RM test. The 1RM test is an indicator of the training regimen's effectiveness in the weeks/months past. To constantly test a 1RM takes time away from the actual process of training, and waiting to assess the effectiveness of a resistance training program only when 1RMs are performed leaves the coach without strong markers of how training is proceeding. Since the back squat and the Brzycki and Epley equations have widespread use in the collegiate weight room setting, it is valuable to know whether or not these equations are accurate for college football athletes in predicting 1RMs for the back squat based on submaximal efforts.

Method

Experimental Approach

The investigation of this project assessed the validity of the Brzycki and Epley equations in estimating the 1RM back squat test results from 3RM and 5RM tests of the same exercise. All participants were tested for their 1RM, 3RM, and 5RM in the back squat exercise. Prior to 1RM testing, participants' body weight and height were also taken for reference. This study was approved by the Southern Illinois Human Research Review Committee.

Table 1: *Equations for Predicting 1RM from Submaximal Efforts*

Brzycki (1993)	1RM = rep wt / [102.78 – 2.78(reps)]
Epley (1985)	1RM = [0.033 (reps)](rep wt) + rep wt

1 RM: 1 Repetition Maximum

Participants

Seventy-nine men 18-23 years of age were recruited from the Sacramento State football team (Division I – Football Championship Subdivision) for the study. Seven participants were not included in the study as a result of not being able to perform the back squat exercise due to injury, four participants were not included because inabilut to complete five repetitions in the 5RM Back Squat Test, and 3 participants were not included due to their inability to complete 3 repetitions in the 3RM Back Squat Test. Overall sixty-five participants were included in the study. Team members included redshirt freshmen, sophomores, redshirt sophomores, juniors, redshirt juniors, seniors, and redshirt seniors. These players had undergone an extensive resistance training program during the previous 9 weeks. The program involved bench press, overhead press, back squat, deadlift, and Olympic lifts (snatch and clean), along with pull ups, barbell rows, glute-ham raises, and various abdominal exercises as supplemental exercises.

Participants lifted on a 3-day-a-week schedule throughout the 9 week training session, working a full body routine each day. The 9 week training session was split into two cycles. During the first 6 weeks of the training program, the players used 3 sets of 5 reps in the core strength exercises (back squat, bench press, overhead press, and deadlift), 4-5 sets of 3 reps in the Olympic lifts, and 3-4 sets of 8-10 reps in the supplemental exercises. For each exercise, the work sets were performed with the same weight for all 3-5 sets. The weight on the bar for the core exercises was increased each session, heavier than the weight used in the session before for that exercise. In the second phase of training, the athletes performed the same exercises as the first 6 weeks but the sets and reps were altered. In weeks 7 through 9, the athletes performed 5 sets of 5 repetitions in the back squat and bench press on the first training day of the week (Monday) at a moderate weight, and then performed a single set of 5 (on week 7) or 3 (week 8) or 1 (week 9) on the last training day of the week (Friday) at a heavy weight. These single heavy sets in the last 3 weeks of training were used for data collection for the trainee's 5RM, 3RM, and 1RM. The other core exercises were performed for 3 sets of 5 reps at increasingly heavier weights, while the Olympic lifts were performed for 6-8 sets of 2 reps. Supplemental exercises were performed for 3-4 sets of 5-6 repetitions. The strength and conditioning coaches dictated the amount of weight on the bar that the athlete would use for each session. The training methodology and programming used for the 9 week training cycle followed the guidelines of The Starting Strength Method, using a Linear Progression in the first 6 weeks of training and a Texas Method protocol for the final 3 weeks of training (Rippetoe & Baker, 2014).

Instruments

All testing was done with the same equipment. The Back Squat test was performed on Power Lift Olympic Platform (Power Lift, Jefferson, IA) measuring 8 feet wide by 4 feet long. All tests were performed using a 45 pound Texas Power Bar (Texas Strength Systems, Austin, TX) and 2.5, 5, 10, 25, and 45 pound Iron Grip Olympic Iron Plates (Iron Grip Barbell Company, Santa Ana, CA). The barbell and weights were supported by a Power Lift Full Rack, 9ft (Power Lift, Jefferson, IA). This equipment was in place at Sacramento State and was used throughout the 9 week summer training along with the testing battery. The mass of the weights was assumed to be within 2% of the stated weight indicated on the plates (this was guaranteed by the Iron Grip Barbell Company, Santa Ana, CA) and the barbell was assumed to be within 2% of the guaranteed weight of 45 pounds (Texas Strength Systems, Austin, TX).

Data Collection Procedures

The Back Squat Test

The back squat test was used to assess lower body muscular strength. The 1RM was the final test to be done, and is considered to be the most accurate assessment of the participant's absolute lower body muscular strength. Participants performed the 1RM back squat test in the last week of a 9 week off-season strength and conditioning program. The 3RM back test was done one week prior to the 1RM back squat test, and the 5RM back squat test was conducted two weeks before the 1RM back squat test. Testing conditions were held constant for each participant for each test, with the 1RM, 3RM, and 5RM tests being performed on the same day of the week, at the same time of day, using the same equipment.

After a standard general warm up, consisting of some light calisthenics and dynamic stretches, each participant was allowed as much time as needed to properly warm up in the back squat exercise. For the 3RM and 5RM testing, under the guidance of the strength and conditioning coach, the individual participant decided upon the number of warm-up sets, warm up weight, and number of repetitions performed to lead them up to their 3RM/5RM back squat test weight. Once the participants were sufficiently warmed up, and having chosen the weights with which they would perform their 3RM/5RM back squat tests, the participants completed the tests with an informed coach watching the set. The lifters were permitted to wear a support belt while squatting. This was at the discretion of the lifter, but all lifters elected to wear a support belt while squatting.

During the performance of the Back Squat, the participant started in an erect position, with the knees and hips fully extended, and the barbell on his back in a position directly below the spine of the scapula, just below the posterior deltoid. The hands were placed on the bar, with all four fingers and the thumb superior to the barbell, trapping the bar between the participant's back and his hands. All participants' feet were flat on the ground and once the bar was lowered, the stance was not allowed to change until the bar was to be repositioned in the support rack at the end of the test. The participant lowered his body to the "bottom" position of the squat, which is defined as the top surfaces of both legs of the hip joint being lower than the knees. This bottom position was identified by the apex of the crease of the hip, the surface of the top of the patella, the plane formed by a straight line between these two points, and the dipping of the hip end of this plane below parallel. Upon reaching the bottom position of the squat, the participant commenced the upward portion of the movement. Once the upward motion of the bar was initiated, any stopping of its upward motion discredited the attempt. At no time were any of the participants allowed to contact his elbows or arms to his legs. The ascent of the squat continued to the finished position of the back squat. The finished position was the same as the starting position. All test measurements were supervised by the primary investigator or an informed strength and conditioning coach at California State University, Sacramento.

In the prior weeks of the off-season training program, the participants had been exposed to heavy back squat sets of 5. This prior training allowed the participants to become accustomed to being underneath a heavy weight and have a better feel for what they could do for a 5RM, 3RM, and 1RM test. By allowing the participants to familiarize themselves with the testing procedures, the individual participants were better able to assess their capabilities in the 3RM and 5RM testing protocol. With this, the strength and conditioning coaches helped to advise the participants were on how to choose their weight for the 3RM and 5RM back squat tests, based on the trainee's prior training history, so as to allow for the heaviest weight to be lifted, without failing to meet the prescribed number of reps for each test (3 reps for 3RM and 5 reps for 5RM).

The pre-testing training sessions, along with the expert eye of the coaches gave each participant the best chance to choose an appropriate weight for the measured 3RM and 5RM back squat tests in the final three weeks of the study.

These procedures were followed for both the 3RM and 5RM back squat tests. For the 1RM back squat test, the participants were taken through the same standard general warm up used for the 3RM and 5RM tests, and were allowed to make decisions upon the number of warm up sets, warm up weight, and repetitions to perform leading up to their first attempt at a 1RM back squat. Researchers have not identified a best warm-up regime for 1RM testing, as it is very individual to the participants being tested, the conditions the testing is being conducted under, and the exercise being tested (Wathen, D. 1994). Despite this, enough warm up sets should be used to raise core temperature and raise levels of arousal/focus (Baechle, 1994). The participants were instructed to warm up as they normally would for a heavy set of back squat, leading up to their first attempt at a 1RM back squat. Participants were allowed to rest 3 to 5 minutes between 1RM attempts (Baechle, 1994.) The weight on the bar was titrated up for each attempt to the heaviest single repetition that the participant could perform successfully. The same standards for a successful squat that were used in the 3RM and 5RM test were upheld throughout the 1RM testing protocol. If the participant failed to complete a repetition, the 1RM back squat testing was stopped for that individual participant. Informed coaches observed all of the 1RM back squat attempts and helped the participants to decide the increase in weight for each 1RM attempt. The greatest weight lifted successfully was recorded as the 1RM. This was usually achieved in three to six attempts. This procedure has been used with high reliability ($r > 0.89$) in similar leg strength testing procedures (Ware et al., 1995; Hoeger et al., 1990).

Spotters were used during the 5RM, 3RM, and 1RM back squat tests. Three spotters were used for each testing attempt, positioned behind and to the side of the lifter. The spotters did not touch the participant during the unloading of the bar from the support racks or during the completion of any successful repetition. At the completion of the last repetition in the 5RM and 3RM Back Squat test, and after the completion of a successful 1RM attempt, the three spotters helped the participant reposition the barbell into the support racks. If a spotter touched the participant at any point during the squat portion of the test (descent or ascent), the repetition was not counted and the test was discredited. If a participant failed during any portion of the test (descent or ascent) the spotters helped the participant and the lift was discredited. Once the finished position of the squat was established for the designated number of repetitions for the corresponding back squat test (5RM, 3RM, 1RM) the spotters helped the participant back into the support racks.

Data Analysis Procedures

1RM Prediction

Predicted back squat 1RMs were estimated from the method developed by Brzycki (1993) and Epley (1985). The Brzycki equation estimates a %1RM from the number of repetitions completed (3 or 5). This %1RM (divided by 100) can then be divided into the submaximal repetitions weight that was used to perform the set of 3 or 5, thus allowing for a prediction of the lifter's 1RM (Table 1). The Epley formula uses a multiple factor of 0.0333 for each completed repetition in the submaximal set to estimate the lifter's 1RM from the submaximal repetition weight (Table 1). The Brzycki and Epley equations are linear.

Statistical Analysis

Pearson product-moment correlation coefficients were used to determine the relationships between predicted and actual back squat performances. Paired *t* tests were used to evaluate the differences between predicted 1RMs and actual 1RMs. Accuracy of the prediction equations was evaluated using the standard error of estimate:

$$\sigma_{est} = \sqrt{\frac{\sum (Y - Y')^2}{N}}$$

An alpha level less than or equal to 0.05 was required for statistical significance.

Results

The characteristics of the 32 collegiate football players participating in this study are listed in Table 2. The 1RM back squat values were 14.2% above the mean scores for college football players given by Ware et al. (1995). The participant's 1RM squat relative to bodyweight averaged 2.02 (±1.08), and was 8.6% above the same measurement for similar players (Ware et al., 1995). Therefore the lower body strength values for the participants were considered representative of college football players.

Strength testing data consisted of the 1RM back squat, 3RM back squat, and 5RM back squat. Table 3 & Table 4 compare predicted and actual 1RM values. For the 3RM squat test, the Brzycki equation significantly underestimated the 1RM by an average of -4.8 kg (±32.2kg) while the Epley equation produced an average 1RM value that did not significantly differ from the actual average 1RM value. Using the 5RM squat test, the Epley equation significantly overestimated the 1RM by an average of 4.0kg (±44.5kg) while the Brzycki equation did not produce an average 1RM that significantly differed from the actual mean 1RM value. The correlation coefficients between predicted and actual squat values were high for the Brzycki and Epley equations when used for 3RM and 5RM tests to predict 1RM. Only the Brzycki equation showed statistical significance ($p < 0.05$) in predicting back squat 1RM from 3RM values, and only the Epley equation showed statistical significance ($p < 0.05$) in predicting back squat 1RM from 5RM values (Table 3 & Table 4).

On average, the weights used to perform the 3RM test were 92.2% (±15.7%) of the participants' 1RM, and the weights used to perform the 5RM test were 87.6% (±18.8%) of the participants' 1RM.

Table 2: *Physical and Performance Characteristics of the Participants*

Variable	Mean	SD	Range
Height (cm)	186.5	8.2	170.2 - 203.2
Weight (kg)	103.8	20.3	78.0 - 153.8
1RM squat (kg)	204.6	22.8	163.3 - 247.2
Squat 3RM weight (kg)	188.7	21.8	145.1 - 229.1
Squat 3RM weight (%1RM)	92.2%	3.9%	82.1% - 97.8%
Squat 5RM weight (kg)	179.1	20.1	138.3 - 215.5
Squat 5RM weight (%1RM)	87.6%	4.3%	74.4% - 93.2%

SD: Standard Deviation; 3RM: 3 Repetition Maximum; 5RM: 5 Repetition Maximum; 1RM: 1 Repetition Maximum

Table 3: *Comparison between 3RM Predicted and Actual Lift Performances*

3RM Test Results						
Strength Measure	Mean	SD	σ_{est} (kg)	r*	t^+	p
Actual 1RM	204.6	22.8				
Brzycki	199.8	23.1	8.5	0.93	3.27	0.0028
Epley	207.3	23.9	8.8	0.93	1.78	0.0844

SD: Standard Deviation; 3RM: 3 Repetition Maximum; 1RM: 1 Repetition Maximum; $\sigma_{est:}$ Standard Error of Estimate; r: Pearson Product Moment Correlation; t: Paired t-test; p: p-value

*Correlation between predicted and actual performance with correlations significant at $p < 0.05$

+Difference between predicted and actual performance with $t = 2.0369$ at $p < 0.05$

Table 4: *Comparison between 5RM Predicted and Actual Lift Performances*

5RM Test Results						
Strength Measure	Mean	SD	σ_{est} (kg)	r*	t^{+}	p
Actual 1RM	204.6	22.8				
Brzycki	201.5	22.7	9.9	0.90	1.75	0.090175
Epley	208.6	23.5	10.3	0.90	2.23	0.033225

SD: Standard Deviation; 5RM: 5 Repetition Maximum; 1RM: 1 Repetition Maximum; $\sigma_{est:}$ Standard Error of Estimate; r: Pearson Product Moment Correlation; t: Paired t-test; p: p-value

*Correlation between predicted and actual performance with correlations significant at $p < 0.05$

+Difference between predicted and actual performance with $t = 2.0369$ at $p < 0.05$

Discussion

This study indicated that 1RM values predicted from submaximal tests using 3RM and 5RM loads were highly correlated with actual 1RM values. The Brzycki equation significantly underestimated the 1RM when applied to 3RM loads, while there were no significant differences between the true 1RM, and the predicted 1RM based on 5RM loads. Despite no statistically significant differences, the Brzycki equation overestimated the 1RM when applied to 5RM loads. The Epley equation significantly overestimated the 1RM when applied to 5RM loads. However, in applying the Epley equation to 3RM loads, there were no statistically significant differences between the predicted 1RM values and the true 1RM values. Although no statistical differences were found, the Epley equation overestimated participants' 1RM based on 3RM performances. In predicting the average 1RM of the sample, the Epley equation was the most accurate when applied to 3RM loads (+2.7kg, 0.013% error), followed by the Brzycki equation applied to 5RM loads (-3.1kg, 0.015% error), then the Epley equation applied to 5RM loads (+4.0kg, 0.020% error), and finally the Brzycki equation applied to 3RM loads was the least accurate in predicting the average 1RM (-4.8kg, 0.024% error).

The Brzycki equation applied to 3RM loads had the smallest range of differences between predicted and actual 1RM values (-24.8kg to 7.3kg), followed by the Epley equation applied to 3RM loads (-18.5kg to 15.4kg), then the Brzycki equation applied to 5RM loads (-33.2kg to 8.8kg), and the Epley equation applied to 5RM loads had the largest range of differences between predicted and actual 1RM values (-27.1kg to 17.4kg). Overall these ranges of difference were not very large and they were all comparable to one another, with the ranges being smaller for estimates based on 3RM performances than estimates based on 5RM performances.

The standard error of estimate for the prediction equations, applied to both 3RM and 5RM loads were comparable to somewhat lower than those seen in Ware et al. (1995). Using the Brzycki and the Epley equations to predict 1RM, the derived standard errors of estimate were moderate, showing that the dispersion of the predicted 1RMs to be relatively close to the corresponding regression line. Both the Brzycki (σ_{est} = 8.47kg) and Epley (σ_{est} = 8.80kg) equations were more accurate in predicting a participant's 1RM when applied to 3RM loads versus 5RM loads. With 5RM loads the Brzycki equation had a lower standard error of estimate (9.94kg) than the Epley equation (10.29kg). This is consistent with the suggestions of Stone and O'Bryant (1987) that loads closer to the 1RM offer better capability for predicting maximal strength. Arnold et al. (1995) and Ware et al. (1995) also noted that heavier loads (greater than 85%) were better for predicting 1RM values than lighter loads in the squat.

Correspondingly, Sobonya and Morales (1987) found that athletes produce better predictions of 1RM squat when using loads greater than 80% of the 1RM. All of the loads used in this study were greater than 80%. The loads used for the 3RM test (92.2% ± 15.7%) were greater than those used for the 5RM test (87.6% ±18.8%), and the 3RM loads produced a higher level of accuracy than the 5RM loads for predicting 1RMs. This further helps to validate the point that submaximal tests that use loads that are nearer to the participant's 1RM offer better predictions of 1RM.

Brzycki (1993) suggests that his equation is most accurate with lower repetition submaximal tests as well. The present results help to confirm this position, as it is seen that the use of 3RM loads is more has a smaller standard error of estimate in predicting a participant's 1RM than 5RM loads. LeSuer and McCormick (1997) reported high correlations between predicted and actual 1RM scores for the squat in college men and women using the Brzycki equation. In their study, subjects chose submaximal weights and squatted until fatigue in 10 or fewer repetitions. The reported correlations were similar to those found in this study, but the average number of repetitions completed and standard errors of the estimate were not given in LeSuer and McCormick (1997). As a result, it is difficult to comprehensively judge the effectiveness of the Brzycki equation, as used in LeSuer and McCormick (1997), on the basis of its accuracy for predicting 1RM with relation to the findings of the current study.

Hoeger et al. (1990) demonstrated that the number of repetitions performed at selected percentages of the 1RM is not the same for all lifts or exercises. In this same study, Hoeger et al. suggested that training may alter the relationship between the repetitions performed in a submaximal test to failure and the predicted 1RM value. Their subjects completed repetitions at 40, 60, and 80% of their 1RM with the leg press exercise as the assessment to quantify lower body strength. Along with this, although the subjects trained in Hoeger et al. (1990) were resistance trained, it is assumed that they had not worked within the intensity ranges of the current subjects. Even if the subjects in Hoeger et al. (1990) had worked within the same intensity ranges as the current subjects, they used isolation exercises on small-muscle groups with machine based training. These exercises vary drastically from the barbell lifts, and a leg press does not equate to a back squat. With this, there are a multitude of factors that come into play when examining the 1RM prediction accuracy of a submaximal repetition test (Braith et al. 1993; Hoeger et al. 1990; Landers, 1985). Factors such as technique, exercises performed, test specificity, and training status all come into play; and to equate a leg press exercise to a heavy back squat is pretentious to say the least. The work of Hoeger et al. (1990) may not provide sufficient information to compare to the current study's assessment of high intensity submaximal testing of the back squat exercise with relation to prediction of 1RMs in trained participants.

The use of well-informed Strength and Conditioning coaches, along with the primary investigator supervising and conducting much of the training and data collection, made the study results more reliable and valid. In reviewing the literature, this is the first 1RM prediction study with elite college football players used as subjects for the testing of 1RM back squat based on 3RM and 5RM submaximal tests. 3RM and 5RM tests are fairly heavy tests with relation to the 1RM, and these loads have not been analyzed in such a manner for the back squat exercise. Most tests performed in much of the exercise science literature utilize a much lighter weight and have the subjects perform repetitions until failure. In the current study, the participants were given a prescribed number of repetitions to complete (3 or 5) in the submaximal test, and the weight that the trainee/coach decided on was used to perform the submaximal test. This is somewhat unique to this study, but is actually what occurs in a collegiate strength and conditioning weight room. Strength and Conditioning coaches do not desire a large number of their athletes to failing underneath heavy loads. Within the strength training session, the athletes are pushed to work towards the higher ends of their strength capabilities, but to still work within their limits. This was the technique utilized for this study, in that the athletes were pushed towards the higher end of their strength ability, but they were not taken to failure within the 3RM and 5RM test. If repetitions were missed in the submaximal test, the test was discredited. Only successful attempts at a 3RM and 5RM were recorded.

Missing squats is not desirable in training of college football players. In testing 1RMs of college football players, there is a greater chance for missing the lift because it is often performed with a weight that the trainee has never handled and it is done with the maximum amount of weight that the system can handle through a full range of motion. Exposing the trainee to such a stress can lead to a greater risk of injury and a higher incidence of failure. In light of the fact that injuring college football players and exposing them to extremely high stressors in the weight room is contraindicated, the use of valid submaximal testing to predict 1RMs is warranted. The purpose of this study was to determine submaximal lifting weights that could be used in 3RM and 5RM tests so as to predict strength without jeopardizing the safety of the trainee. There were no reported injuries after the 3RM and 5RM tests and the data collected allowed for assessment of the Brzycki (1993) and Epley (1985) as they relate to the back squat exercise with heavy submaximal weights.

By examining the means of the predicted 1RMs against the actual tested 1RMs, the Epley equation (+2.7kg) was closest to the true 1RM when applied to the 3RM submaximal test results. For the 5RM submaximal test, the Brzycki equation (-3.1kg) most closely predicted the participants' 1RM over the Epley equation (+4.0kg). The Brzycki equation tended to under-predict the participant's 1RM for both submaximal tests, whereas the Epley equation tended to over-predict the participant's 1RM for both submaximal tests. Understanding these results in the practical setting, it can be seen that different equations are better applied to different submaximal tests. This is consistent with the findings of Hoeger et al. (1990), even though the back squat exercise is examined in the current study and the leg press is used in Hoeger et al. (1990). Whisenant et al. (2003) also had similar findings in that different equations are better predictors of 1RMs for different rep ranges used in submaximal testing. Based on the results of the current study, it can be seen that the Epley equation is a better predictor of 1RM strength for the back squat exercise in college football players, when applied to 3RM loads. When using a 5RM submaximal back squat test, it is best to use the Brzycki equation to predict 1RMs.

The research hypothesis examined in this study was that the Epley equation is more accurate than the Brzycki equation in predicting 1RM capabilities, and that when using these equations; the 3RM back squat load is more accurate than the 5RM back squat load for predicting a participant's 1RM. This was shown to be partially false through the findings of this study. The Epley equation was more accurate than the Brzycki equation in predicting 1RM capabilities, but only when applied to the 3RM submaximal test. This finding is further bolstered by the fact that there were no significant differences between the mean predicted 1RM and true tested 1RM when using the Epley equation to predict 1RM values from 3RM loads. The opposite findings were found when examining the 5RM back squat test: the Bryzcki equation was more accurate than the Epley equation in predicting 1RM capabilities, but only when applied to the 5RM submaximal test. With this, the data showed the Brzycki equation's predictions of mean 1RM values were not statistically different from the true measured 1RM values. Overall the research hypotheses was partly correct, in that the overall most accurate prediction equation to use was the Epley equation when applied tothe 3RM back squat test. Despite this, there were differences in which prediction equation demonstrated higher accuracy for each submaximal test. The Epley equation demonstrated more accuracy in only the 3RM test. However, the Brzycki equation produced more accurate predictions of 1RM values when applied to 5RM submaximal tests. Also, the 3RM test (3.8kg) on average did not elicit any more accurate predictions of 1RM than the 5RM test (3.6kg). The accuracy of the test for predicting the 1RM was dependent upon which equation was used to predict the 1RM. The 3RM test was more accurate when the data was applied to the Epley equation, but the 5RM test was more accurate when applied to the Brzycki equation. To recap: the research hypothesis was shown to be partially false, since the 3RM back squat test was not always the most accurate test for predicting the college football player's 1RM, and the Epley equation was not always the most accurate prediction equation to use.

Although in the current study the validity of the prediction equations varied with repetition ranges and submaximal load used, more research is needed. Demographic variables, race, age, height, weight, fat-free mass, and percent body fat are all considerations that come into play when predicting a 1RM based on submaximal testing (Whisenant et al. 2003). Further research on the effects that these factors play in predicting 1RMs based on relatively heavy submaximal tests in the back squat needs to be conducted. Also, because of the small sample size, generalization of the findings to the collegiate football population as a whole is not warranted. Additional research needs to be done with a population that is larger in size and also performs tests utilizing 3RM and 5RM tests to predict 1RMs.

Practical Applications

With the growing trend of collegiate strength and conditioning programs using the back squat as the primary lower body strengthening exercise, the responsibility of the strength and conditioning coach to find a safe and effective means to predict maximal strength has become a crucial matter. The results of the current study have demonstrated that the validity of the Brzycki and Epley equations, as applied to the back squat exercise, is dependent upon the number of repetitions performed. If a 3RM test is employed as the submaximal test used to predict a trainee's 1RM, the Epley equation should be used. When using a 5RM submaximal test, the Brzycki equation is the better choice to predict the athlete's 1RM. Overall further research needs to be done on a larger population, but the present results indicate that there is promise in accurately predicting a college football player's strength capabilities based on 3RM and 5RM testing.

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