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Predicting Maximum Concentric And Eccentric Squat Strength From Maximum Isometric Squat Strength

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BIOLOGY

ABSTRACT

Resistive squat exercise is a well-established technique to enhance the strength of muscles and bone of the back in humans. Such type of exercise could prove highly beneficial for individuals with pathological condition of the back such as osteoporosis. Notably, the rehabilitation programs aimed at strengthening the muscles and bone of the back require the knowledge of the patient's one repetition maximum (1RM). Finding the 1RM squat value could lead to injury due to the higher weights involved. In addition, testing for 1RM could be not feasible in older populations or young population with chronic back conditions The isometric squat serves as the safest squat type in terms of injury due to the nature of the muscular activity that takes place versus the concentric and eccentric squat types. My study sought to investigate the predictive relationship between the maximum isometric squat strength and the maximum concentric and eccentric squat strength in young and older individuals. In addition, I also examined the predictive ability of prone back extension exercise to predict the concentric and eccentric 1RMS in young and older adults.

Individuals from two age populations, 21-35 years (young) and 55-75 years (older), were recruited and participated in two visits within a two-week period. The study found that the maximum isometric squat was a significant predictor of the concentric ($p < 0.05$, NormalizedConMax=.708 + 1.376(NormalizedIsoMax)) and eccentric 1RM squat maximums ($p < 0.05$, NormalizedEccMax= .844+1.433(NormalizedIsoMax)) in older adults only. Prone back extension repetitions a participant was found to be a significant predictor of the eccentric squat 1RM in older adults ($p<0.05$; NormalizedEccMax =0.714 + 0.030(PBERM)) and a significant predictor of the concentric squat 1RM in younger adults ($p < 0.05$, NormalizedConMax=0.448 +0.054(PBERM)). Study findings and the novel equations provide data to predict the 1RM concentric and eccentric squat values necessary for designing the rehabilitation regimes for enhancing musculoskeletal status of the back in humans.

Keywords: Rehabilitation, Spine, Bone, Older, Osteoporosis

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CHAPTER 1

INTRODCUTION

The evolutionary history of humanity has led to adaptations of the human spine that have altered its structural design. For example, one of the major adaptations of the human spine is the development of the four curvatures of the spines in the cervical, thoracic, lumbar, and sacral regions. Indeed, the curved structure of the human spines is unique to the species, as other apes demonstrate a single long C shaped spine (Galbusera & Bassani, 2019). The resulting changes in the structural design of the human spine could represent evolutionary tradeoffs predisposing the human spine to degradation and injury. The spinal curvatures could increase the injury risk to the human spine versus the apes, especially at the lumbar spine where its forward curvature is deemed at being at higher risk of fractures (Plomp et al, 2019). The presence of specialized structural components of the thoracic and lumbar spine such as shorter pedicles and longer transverse processes of the upper thoracic vertebrae and longer laminae of the lumbar vertebrae in humans corroborate the hypothesis of effect of the unique bipedal locomotion of humans on the human's spinal column (Selby et al, 2019) (Plomp et al, 2020) (Plomp et al, 2019).Thus, the unique shape and structure of the human spine along with the bipedal nature of humans are possible reasons why humans suffer more commonly from injuries or chronic conditions of the spine than other primates (Plomp et al, 2015) (DeRousseau, 1992).

Squatting is one of the basic movements, which is critical for performing activities of daily living as well as leisure-time activities (Myers at al. 2014). The act of lifting and lowering a load against a resistance in a squat position, also known as resistive squat exercise, is utilized in rehabilitation programs to create anabolic stimulus on the muscles and bones of the vertebral column and lower limbs of the body (Wilk et al, 2018). Typically, designing resistive exercise programs for specific muscles during specific movements requires testing for the one repetition maximum (1RM) strength for the corresponding muscle performing the specific movement. For example, the 1RM of the squat exercise is the highest amount of weight one can lift and lower during a squat in a single repetition (Schoenfeld et al, 2021) (Blazevich et al, 2002) (Cormie et al, 2007). In healthy populations the 1RM maximum can be found by having an individual perform one repetition squats with increasing loads until they fail to lift and thus achieve their 1RM. The 1RM of the squat exercise is a reliable test in trained and untrained young adults. (Mccurdy et al, 2004) (Grgic et al, 2020). To our knowledge, there is no information whether 1RM squat exercise is reliable in older adults, which might be due to the potential risk of injury associated with 1RM squat testing in older adults. In fact, older adults with clinical conditions affecting the spine, such as osteoporosis, may be highly susceptible to injury from the high load nature of the load being lifted (Braith et al, 1993) (Shaw et al, 1995) (Shirado et al, 1995). There are increasing reports of early onset of osteopenia or osteoporosis in young adults (Salari et al, 2021). Thus, young adults with conditions such as osteoporosis may also be at an increased risk for spinal injury from the high load nature of the load being lifted during 1RM determination. Thus, there is a specific critical need to design novel ways to test the 1RM of the squat exercise in young adults and older adults with musculoskeletal conditions affecting the spine. A safe way to assess 1RM could help design scientifically effective rehabilitation programs to strengthen the spine in young adults and older adults with musculoskeletal conditions.

The squatting movement can be broken down into three distinct phases with each phase corresponding to unique muscular contraction types. The large back muscles that are activated during a loaded squat are the erector spinae muscle group, consisting of iliocostalis, longissimus, and spinalis. The unique muscular contraction types of the erector spinae group occur at different phases of the squatting movement are as follows: eccentric (muscle lengthening) contractions during the lowering phase, concentric (muscle shortening) contractions during the rising phase, and isometric (minimal to no change in muscle length) contractions occurring between the end of the lowering phase and the start of the rising phase of the squat. Typically, isometric contractions versus concentric and eccentric contractions have the lowest risk for movement-related injury, and thus have been widely used in clinical settings as a means of measuring the force generation capabilities of muscle groups (Lum et al, 2020). Previous studies have demonstrated that there is a positive relationship between the maximum isometric squat strength and free bar squat 1RM, and the isometric squat can be utilized to predict the free bar squat 1RM in young individuals of both the sexes (Blazevich et al, 2002) (Petrović et al, 2020) (Parai, 2016). The diagnostic and prognostic values of the maximum isometric squat contractions is further underpinned by its utility to quantify effectiveness of back strengthening rehabilitation programs while also being less fatiguing and easier to perform than concentric or eccentric contractions (Warneke et al, 2023) (Drake et al 2018).

The maximum concentric strength is the main determinant of the conventional 1RM testing because the 1RM testing involves testing a muscle for the maximum amount of load it can lift. The 1RM value thus obtained is utilized to design progressive resistive squat exercise program for musculoskeletal rehabilitation program for the back muscles and the spine. Notably, muscular force generated via eccentric contractions is significantly higher than concentric contractions (Nuzzo, 2013). Thus, for a given 1RM, the eccentric contractions might be loaded sub optimally or potentially below the anabolic potential for the progressive resistive squat exercise program. Since eccentric and concentric loading create differential loading patterns (tensile vs compressive) on bone, it is imperative to load the concentric and eccentric maximally for the maximal desired therapeutic outcome and designing an effective progressive resistive squat exercise program. The importance of differentiating 1RM unique for concentric and eccentric contractions becomes more important with aging. It is known that the eccentric strength of muscles is more greatly retained with age in comparison to concentric strength (Roig et al, 2010). The retention of eccentric contraction strength with aging comes from the contribution of titin and other associated structures that do not decline as greatly in capability as the myosin structures of muscles (Roig et al, 2010) (Power et al ,2016) (Miller et al, 2013) (Hessel et al, 2017) (Herzog, 2018) (Nuzzo et al, 2023). Noticeably, eccentric muscle contractions are more energy efficient than concentric contractions for the given amount of muscle force and thus, are more beneficial than concentric contractions for the cardiovascular system (Hessel et al, 2017) (Herzog, 2018). Thus, it is necessary to know the 1RM of both types of contractions, potentially to create scientifically informed and effective rehabilitation programs for strengthening bones of the vertebral column.

The maximum isometric squat strength has been utilized to predict the full squat 1RM in young adults, but the relationships and possible predictive capabilities between the isometric squat maximum and the unique concentric and eccentric maximum 1RM squat does not exist (Blazevich et al, 2002) (Demura et al, 2010) (Petrović et al, 2020). A knowledge of how the maximum isometric squat strength relates to the concentric and eccentric squat maximums could help in the design of novel back strengthening rehabilitation programs creating specific anabolic stimuli for both the concentric and eccentric phases of the squat exercise. Such an approach can be especially important for musculoskeletal rehabilitation programs for older adults with chronic conditions of the skeletal system, such as osteoporosis (Haczynski & Jakimiuk, 2001).

The prone back extension exercise, which is performed by asking the patients to lay prone on a plinth and lift their upper thoracic region off the plinth for as many repetitions as they can in a set time frame, is one of the well-established clinical techniques to assess back muscle strength (Goyal et al, 2013). The prone back extension exercise has been used to increase the overall muscular strength of the back extensor muscles and reduce extension with no resistance added has been posited to limit load placed on the spine during the exercise while still retaining the strengthening and strength assessing capabilities of the exercise. Thus, the prone back extension exercise is deemed a safe exercise to increase back muscles strength for aged or clinical populations (Sinaki et al, 2012) (Goyal et al, 2013). It is unknown if an individual's performance of the prone back extension exercise can predict the maximum concentric and eccentric contractions. Such information can be highly translatable to clinical settings to design the appropriately dosed exercise for designing a progressive resistive concentric and eccentric squat exercise program in older adults, especially in situations where testing for the 1RM is not feasible due to fear of injury or lack of appropriate and safe equipment.

Thus, the main purpose of this study was to determine if isometric maximum squat strength can predict maximum concentric and eccentric squat strength in young and older adults. A secondary aim of this study was to determine if the prone back extension exercise can predict maximum concentric and eccentric squat strength in young and older adults. We hypothesized that isometric maximum squat strength and prone back extension exercise will predict maximum concentric and eccentric squat strength in young and older adults.

CHAPTER 2

METHODOLOGY

Participants

We collected and analyzed data from 29 participants in our study. A prior power analysis was used to estimate the required sample size for the study. The statistical analysis was set for a linear regression: fixed model, single regression coefficient with an effect size (f2) of 0.7, alpha error probability at 0.05, and power at 0.8. The calculated sample size was found to be 14 participants per group. Our sample size is in line with a previous study with similar outcomes. (Blazevich et al, 2002). The participants were classified in 2 groups: young (21-35 years, n = 15, men = 9, women = 6) and older adults (55-75 years, n = 14, men = 8, women = 6).

We did not test anyone with a condition that limited their physical ability to fully perform our study's tests. Specific exclusion criteria included the following conditions: (1) uncontrolled diabetes; (2) uncontrolled hypertension; (3) metal screws/plates/rods in the body; (4) back surgery/myocardial infarction/congestive heart failure/cataract surgery/stroke within previous 6 months; (5) known prior vertebral fracture; (6) known fragility fracture within the last year; (7) tobacco use within the previous 10 years; (8) current use of medications that affect muscle/bone, such as hormone replacement therapy or corticosteroids; (9) back pain; and (10) uncontrolled hernia. The University of Alabama at Birmingham institutional review board approved this study.

Study Design

Our study used a cross-sectional design to collect data from local populations for both the age groups being examined. Our study consisted of two visits to the Physical Therapy Research Laboratory. Both the visits were at least a week apart from each other, but no more than two weeks apart. The reason for the second visit was to allay any learning effect that may have occurred with the participants or to find their 1RM if it was not obtained during their first visit. We obtained the informed consent from our participants during their 1st visit. In addition, we performed anthropometric measurements during their 1st visit. For both the visits, we assessed the maximum isometric squat strength test first. Next, based on a simple randomization technique, we determined the order of testing of the concentric and eccentric 1RM squat strength test, unique to each participant. The 2nd visit consisted of squat strength testing with the maximum isometric squat strength testing performed first followed by the same randomized order of concentric and eccentric 1RM squat strength test per the 1st visit of each participant. For both the visits, prone back extension exercise testing was assessed at the last.

Anthropometric Measurements

At the first visit only, participants had their height taken in centimeters using a wall stadiometer (Novel Products Inc, Rockton, Illinois) and then had their weight taken in kilograms using a digital physician’s scale (Tanita Corporation of America, Arlington

Heights, Illinois). We calculated Body Mass Index (BMI) using the formula, weight divided by height squared (kg/m2).

Warmup

To limit the risk of injury, individuals were asked to perform a warmup session before the testing. The warmup session consisted of participants using a stationary cycling bike or an elliptical machine for five minutes at a comfortable pace. In the last thirty seconds of the 5-minute warm up session, participants were asked to further slowdown and keep the warm-up exercise to a minimum to prevent fatigue. Next, participants were provided a rest interval of 90-seconds before any testing.

Goniometer

Wireless digital goniometers (Biometrics Corp., UK) were used to record and examine the angles of the knees and back of the participants at different points in the study. The knee goniometer was utilized to find the appropriate depth for the squat position. The goniometer was placed on the lateral aspect of the dominant leg's knee. Specifically, the knee goniometer crossed the knee joint, with one end placed on the distal end of the femur and the other on or near the head of the fibula. To identify the dominant leg, participants were asked what leg they would kick a ball with. Data from the goniometers were relayed to the computer with the Biometric data analyst application that received, analyzed, and recorded the positioning and angle of the goniometer. Finally, the wireless goniometer secured on the lower back of the participant was used to record the number of repetitions for the prone back extension exercise. One complete wave, trough to trough, represented the completion of a single back extension repetition.

A total count of the full number of complete waves during the 30-second time for the prone back extension exercise was performed to assess the performance on the prone back extension exercise.

Maximum Isometric Squat Strength Test

Our set up for testing the maximum isometric squat strength test via a Smith Machine and high-performance strain gauge indicator is shown in Figure 1 along with the starting position for the eccentric and concentric squat. All our squat strength testing was performed at a 45-degree flexion angle of the knee (45.91±3.09). The partial squat (a 45-degree flexion angle of the knee) position was chosen for all the squat testing trials instead of a full squat because the partial squat may be a safer option than the full deep squat while still maintaining the anabolic stimulating capabilities of the squatting exercise on the back muscles (Hartman et al, 2013). The partial squat has also been identified to activate the various muscle groups that are utilized during a squat at different levels than the full deep squat (Silva et al, 2017). For example, partial squat can specifically increase the activity of the erector spinae muscle group, which are also the targeted muscles of the prone back extension exercise (Silva et al, 2017) (Caterisano et al, 2002).

A. B. C.

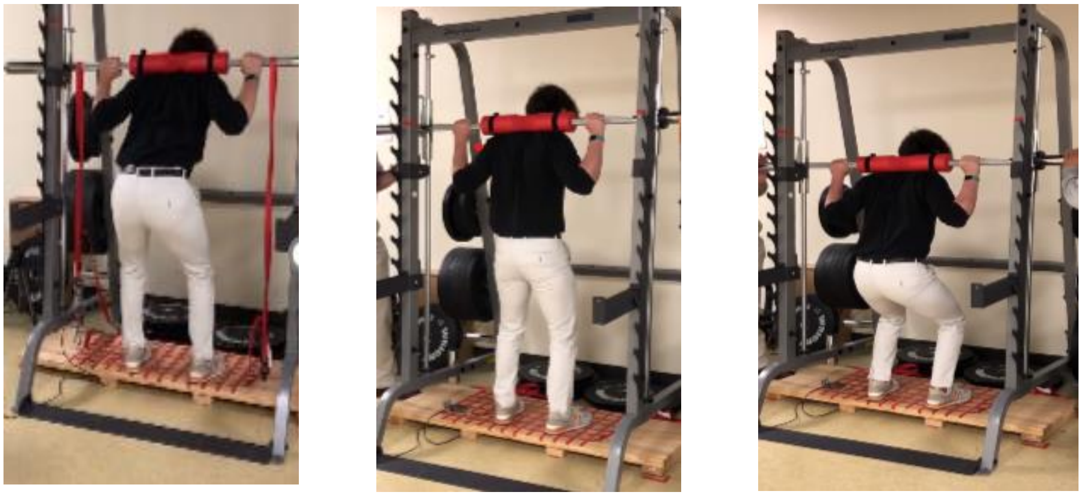

Figure 1: Example of maximum A) isometric, B) eccentric, and C) concentric squat strength tests.

Individuals were asked to slowly descend in the squatting form until they achieved a forty-five-degree flexion angle of the knee as registered by the wireless goniometer. At this point, the location was marked, and the Smith Machine was locked into this position for the bar to be stationary during the isometric squat tests. The maximum isometric squat strength test via a Smith Machine was the first of the squat tests performed during both the trial visits for every individual. To record the isometric force exerted, a high-performance strain gauge indicator (Omega, Norwalk, Connecticut) was utilized by attaching it to the bar of the Smith machine and the stabilizing wooden plate below the bar to record the isometric data. The force exerted upon the bar and the plate below was recorded in pounds.

Participants were first familiarized with the test by trying to perform the test with submaximal force. Then for the testing, participants were asked to exert as much force as they could on the bar and maintain it for five seconds. With the bar being locked in place, an isometric muscular contraction occurred. To limit the risk of injury and to help in the maintenance of form, participants were instructed and guided into a proper squat form, with the presence of a good lumbar curve being the main determinant of form. While this occurred, the strain gauge recorded the force exerted upon the bar and displayed the maximum amount of force exerted during each trial. Each participant was asked to perform five of these isometric tests during each visit with 90 seconds of rest interval between each trial. A trial was deemed a failure if the force exerted peaked and dipped repeatedly during the trials, and a member of the testing team monitored the force measurer to view this.

1RM Concentric and Eccentric Squat Strength Tests

The 1RM concentric and eccentric squat strength trials occurred after the isometric squat for every participant as described above. In short, for each participant, the order of the two tests was randomized, but the second visit for each participant would use the same order for these tests as their first visit. The goal of each test was to find the 1RM for the squat type being assessed. Both tests would involve the participant performing only the squat type being assessed with the weighted bar of the Smith machine. The initial weight loaded onto the bar was determined from the isometric force maximum they exerted and the participant's body weight. After each trial, the weight would be increased based on the difficulty rating (as described below) that was given by each participant and the consideration of how well their form was maintained. Along with the presence of a good lumbar curvature, a good form also meant a controlled ascension or descension of the bar. The participant would not perform the other squat type for each trial, and the bar would be returned to its original position by the research team. The starting position of each squat is shown above in figure 1.

Each test would have a maximum of 8 trials performed during a visit to limit muscle strain and risk of injury. A trial was deemed a failure if an individual could not complete the squat fully or there was a major loss of form, such as a shaky movement or loss of the lumbar curve. After each trial, participants were asked to rate the difficulty of that trial, and this would influence how much weight was added to the bar. This difficulty rating was taken using the Borg Rating of Perceived Exertion scale, a tool developed by Swedish Scientist Gunnar Borg (Williams, 2017). This scale allows for the assessment of an individual's fatigue, exertion and effort using a scale from 6 to 20, with each number of the scale corresponding to certain difficulty level and a heart rate of ten times the number given (Williams, 2017). A difficulty of 6 means no exertion and corresponds to heart rate of 60 beats per minute, while a difficulty of 20 means that the participant believed they were giving their maximum exertion possible (Williams, 2017). The 1RM for the squat type being tested was determined if one of three following events occurred. 1) The participant was incapable of moving the bar at all from its resting position. To ensure this was the 1RM, the bar would have its load lowered and participants would try again with a lower weight. 2) The squat movement became unsteady or quick during ascent or descent. This often coincided with a loud bang from the bar being placed into position too quickly. 3) The participant gave a difficulty rating of 20.

The concentric 1RM squat strength test consisted of finding the 1RM for the concentric squat, which involved the raising of the bar. The bar was first placed at the same position as the isometric bar. The participant would raise the bar in a controlled and slow manner until they reached completion at the standing squat position. At the end, the bar would be locked in place and the weight taken by the researchers. The bar would be returned to its original position between each trial by the research team to prevent the participant from performing the eccentric squat. The tests would precede with the instructions and conditions written above until a maximum was reached or until all 8 trials for the visit had been performed.

The eccentric 1RM squat strength test sought to find the 1RM maximum for the eccentric squat for each participant. This test involved bringing the bar down from their standing squat position. The squat was complete when it reached the safety bars placed at position where the knee angle was 45 degrees. The Smith machine bar was locked in this eccentric starting position through hooks found on the bar that could lock into the holes of the machine. The tester made sure the Smith machine's bar was fully rested on the participant's shoulder before the participant was instructed to bring the bar down to the resting stop in a controlled manner. Next, the research team would raise the bar to prevent the participant from performing a concentric squat during these tests. The tests would precede with the instructions and conditions written above until a maximum was reached or until all 8 trials for the visit had been performed.

Prone Back Extension Exercise

The last test performed at the end of each visit for every participant was the prone back extension test. This consisted of two trials where the participant was tasked with performing as many back extensions as they could during a 30 second period. This test was performed with the participants lying prone with their hands behind their head. The participant was aided by a research member who would stabilize their lower body by holding down their legs. All participants were asked to extend their back as high as they could with the back extension movement.

The wireless goniometer on the back was utilized to record the data for each prone back extension trial. The goniometer was zeroed with each participant in the starting condition. During the trials, the goniometer would record and present a line with waves, with the trough of each wave representing the negative angle they reached upon raising their upper body. A full back extension was defined as one trough to trough. Figure 2 below presents an example of one of the recordings for the prone back extension trial of a participant. The negative value of the trough is a result of the way the goniometer recorded the angle of the back being extended.

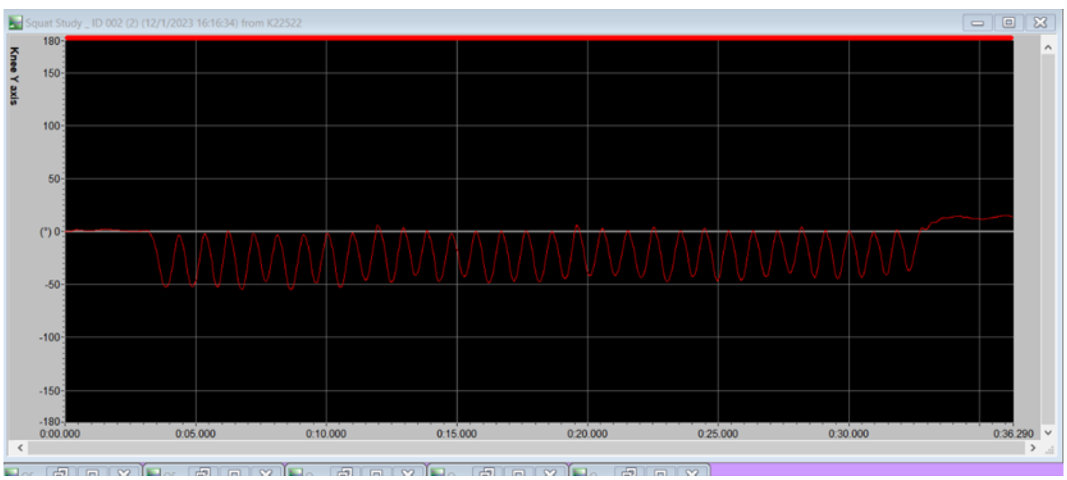

Figure 2. Example of prone back extension trial recording

Statistical Analysis

Data was checked for normality using the Shapiro-Wilk test of normality (Table 3). This test was chosen for its capability to test for normalcy in lower populations. The descriptive statistics of both the young and older adult s are presented as mean □

standard deviation (SD) (Table 1). The results for the recorded maximum squat strength for each of the three squat types was normalized to body weight, and the maximum prone back extension repetitions for both age groups are recorded as mean ± SD (Table 2). This normalization was performed to address the proportional bias of different body weights and their resulting effect on absolute squat strength results. The analysis of the descriptive statistics was done using independent sample T-tests. Linear regression was performed to analyze the relationship between the isometric squat maximum and the concentric and eccentric 1RM values in both age groups. Linear regression was also utilized to analyze the relationship between the maximum prone back extension repetitions and the maximum value for all three squat types in both age groups. The accepted alpha value was $p < 0.05$ in all statistical tests. Effect size for group differences (young vs older) in maximum isometric squat strength, 1RM concentric squat and eccentric squat strength were assessed using Cohen’s d where the values of Cohen’s d of 0.2, 0.5, and 0.8 represented small, medium, and large effect sizes (Cohen, 1988).

CHAPTER 3

RESULTS

Table 1. Physical characteristics of study participants

Variables	Participants (n = 29)		Two-Sided P
	Young (n = 15)	Older (n = 14)	
Age, y	23.67 ± 3.266	58.64 ± 2.925	<0.001
Body weight (kg)	71.233 ± 13.424	83.287 ± 12.718	0.020
Height (M)	1.689 ± 0.098	1.737 ± 0.101	0.209
BMI kg/m^2	24.862 ± 3.651	27.634 ± 3.816	0.056

Abbreviations: BMI, Body Mass Index

The physical characteristics of study participants are shown in table 1. The participants in the study were broken into two groups of younger adults, ages 21-35 years, and older adults, ages 55-75 years. Age and weight differences were found to be statistically significant between the two age populations ($p < 0.05$), but height and BMI were found to not be statistically significantly different ($p > 0.05$). There was a trend toward significance ($p = 0.056$) for a heavier BMI for older vs young adults.

Table 2. Squat maximum and maximum prone back extension repetitions

Variables	Participants (n = 29)		Two-Sided P	Effect size Cohen's *d*
	Young (n = 15)	Older (n = 14)		
Iso Max (kg)	54.07 ± 27.54	45.4 ± 15.6	.306	0.39
Ecc Max (kg)	175.8 ± 53.6	133.8 ± 30.04	.016	0.96
Con Max (kg)	171.80 ± 54.8	119.8 ± 26.8	.004	1.2
Normalized Iso Max	0.739 ± .291	0.565 ± 0.242	.092	0.65
Normalized Ecc Max	2.494 ± 0.749	1.653 ± 0.477	.001	1.33
Normalized Con Max	2.447 ± 0.794	1.485 ± 0.451	<.001	1.49
Prone Back Extension Repetition Max	37.07 ± 8.242	31.43 ± 8.803	.086	0.66
Abbreviations: Iso, Isometric; Ecc, Eccentric; Con, Concentric; Max, Maximum				

The average maximum for all three squat types and the prone back extension repetition maximum (PBERM) is presented in table 2. The table presents the values for both the absolute squat maximum and the normalized to body weight values. Both the absolute and normalized concentric and eccentric squat 1RM strength measures were found to have statistically significant differences between the two age populations ($p < 0.05$, $d = 0.96$-1.49) with young adults showing greater values than older adults. The absolute isometric maximum, the normalized isometric maximums, and the prone back extension repetition maximums were found to not be significantly different between the two age groups ($p > 0.05$). Notably, a moderate effect size difference ($d = 0.65$-0.66) was noted for normalized isometric squat maximum and prone back extension difference between young and older adults with older adults vs young adults showing lower values of normalized isometric squat maximum and prone back extension repetition performance.

Table 3. Normalcy results from Shapiro-Wilks test of normalcy in younger adults (A) and older adults (B)

A.

Variable	Statistic	Shapiro-Wilk df	Sig
Normalized Iso Max	.937	15	.350
Normalized Ecc Max	.934	15	.309
Normalized Con Max	.926	15	.238
Prone Back Extension Repetition Max	.938	15	.361

B.

Variable	Statistic	Shapiro-Wilk df	Sig
Normalized Iso Max	.901	14	.116
Normalized Ecc Max	.939	14	.409
Normalized Con Max	.910	14	.158
Prone Back Extension Repetition Max	.912	14	.170

Table 3 presents the result of the Shapiro-Wilk normalcy test performed for both age groups. Analysis of the data for both age groups found all the data from the four analyzed variables to be within normal distribution ($p > 0.05$). We chose the Shapiro-Wilk test for its capability to better analyze populations under the sample size of 50.

Table 4. Linear Regression analysis of normalized isometric maximum vs normalized eccentric and concentric maximums in whole population (A), young adults (B), and older adults (C).

A.

Dependent	Predictor	Unstandardized B Constant	Unstandardized B Predictor	Standardized β-Coefficient	$r_{partial}$	95% Confidence Interval	P
Normalized Ecc Max	Normalized Iso Max	1.015	1.639	.605	.605	0.786-2.491	<.001
Normalized Con Max		0.810	1.790	.618	.618	0.891-2.689	<.001
β-Coefficients display changes in SD in dependent variable per SD change in independent variable							

B.

Dependent	Predictor	Unstandardized B Constant	Unstandardized B Predictor	Standardized β-Coefficient	$r_{partial}$	95% Confidence Interval	P
Normalized Ecc Max	Normalized Iso Max	1.622	1.180	.459	.459	-0.189-2.549	0.085
Normalized Con Max		1.439	1.364	.500	.500	-0.052-2.779	0.058
β-Coefficients display changes in SD in dependent variable per SD change in independent variable							

C.

Dependent	Predictor	Unstandardized B Constant	Unstandardized B Predictor	Standardized β-Coefficient	$r_{partial}$	95% Confidence Interval	P
Normalized Ecc Max	Normalized Iso Max	0.844	1.433	.727	.727	0.582-2.284	0.003
Normalized Con Max		0.708	1.376	.737	.737	0.583-2.169	0.003
β-Coefficients display changes in SD in dependent variable per SD change in independent variable							

Table 4 is broken down into three separate tables that present the predictor capabilities and relationship of the normalized isometric maximum in relation to the normalized 1RM concentric and eccentric contractions in different populations. This analysis was performed by utilizing linear regression. In the whole participant population, the normalized isometric maximum was found to be a significant predictor of 1) normalized eccentric squat maximum ($p = <0.001$, $B = 1.015$, $ß = .605$, $r_{partial} = 0.605$) and 2) normalized concentric squat maximum ($p = .001$, $B = 0.810$, $ß = .618$, $r_{partial} = 0.618$). In younger adults, the normalized maximum isometric squat was not found to be a significant predictor of either the normalized eccentric or normalized concentric squat maximums ($p > 0.05$). In older adults, the normalized maximum isometric squat was found to be a significant predictor of 1) normalized eccentric squat maximum ($p = 0.003$, $B= 0.844$, $ß = .727$, $r_{partial} = 0.727$) and 2) normalized concentric squat maximum ($p = 0.003$, $B = 0.709$, $ß = .737$, $r_{partial} = 0.737$).

Table 5. Linear Regression analysis of prone back extension repetition maximum vs normalized eccentric, concentric, and isometric maximums in whole population (A), younger adults (B), and older adults (C).

A)

Dependent	Predictor	Unstandardized B Constant	Unstandardized B Predictor	Standardized β-Coefficient	$r_{partial}$	95% Confidence Interval	P
Normalized Ecc Max	Prone Back Extension Repetition Max	0.442	0.048	.562	.562	0.020-0.076	0.002
Normalized Con Max		0.153	0.053	.585	.585	0.024-0.082	<0.001
β-Coefficients display changes in SD in dependent variable per SD change in independent variable							

B)

Dependent	Predictor	Unstandardized B Constant	Unstandardized B Predictor	Standardized β-Coefficient	$r_{partial}$	95% Confidence Interval	P
Normalized Ecc Max	Prone Back Extension Repetition Max	0.916	0.043	.469	.469	-0.005-0.091	.078
Normalized Con Max		0.448	0.054	.560	.560	0.006-0.102	0.030
β-Coefficients display changes in SD in dependent variable per SD change in independent variable							

C)

Dependent	Predictor	Unstandardized B Constant	Unstandardized B Predictor	Standardized β-Coefficient	$r_{partial}$	95% Confidence Interval	P
Normalized Ecc Max	Prone Back Extension Repetition Max	0.714	0.030	.552	.552	0.001-0.058	0.041
Normalized Con Max		0.673	0.026	.504	.504	-0.002-0.054	0.066
β-Coefficients display changes in SD in dependent variable per SD change in independent variable							

Table 5 is broken down into three separate tables that present the predictor capabilities and relationship of the prone back extension repetition maximum in relation to the normalized 1RM concentric and eccentric squat contractions and the normalized isometric squat maximum in different populations. This analysis was performed by utilizing linear regression. In the whole participant population, the prone back extension repetition maximum was found to be a significant predictor of 1) normalized eccentric squat maximum ($p = 0.002$, $B = 0.442$, $ß = .562$, $r_{partial} = 0.562$) and 2) normalized concentric squat maximum ($p < 0.001$, $B = 0.153$, $ß = .585$, $r_{partial} = 0.585$). In younger adults, the prone back extension repetition maximum was found to be a significant predictor of normalized concentric squat maximum ($p = 0.030$, $B = 0.448$, $ß = .56$, $r_{partial} = 0.56$). The prone back extension repetition maximum was not found to be a significant predictor of the normalized eccentric squat maximum ($p > 0.05$). In older adults, the prone back extension repetition maximum was found to be a significant predictor of normalized eccentric squat maximum ($p = 0.041$, $B = 0.714$, $ß = .552$, $r_{partial} = 0.552$). In older adults, the prone back extension repetition maximum was found to not be a significant predictor of normalized concentric squat maximum ($p > 0.05$).

The following equation is the novel regression equation predicting normalized concentric maximum based on PBERM in young adults, as shown in figure 3. In figure 3, dotted lines are representative of 95% confidence interval range.

$$NormalizedConMax = 0.448 + 0.054(PBERM)$$

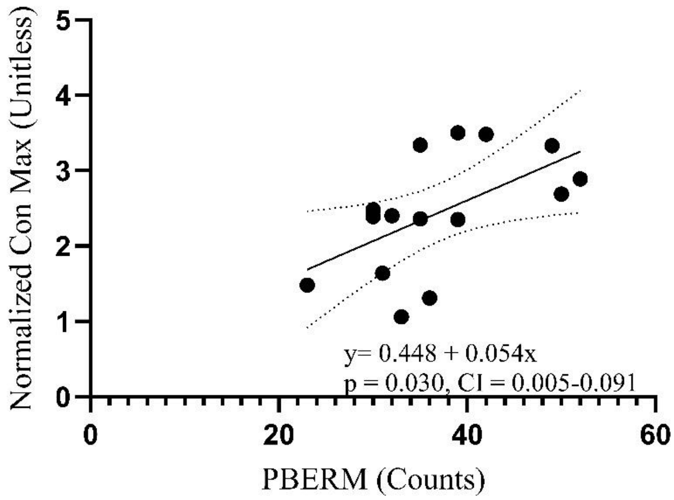

Figure 3. Linear regression of prone back extension repetition maximum vs normalized concentric maximum in young adults.

The following equation is the novel regression equation predicting normalized eccentric maximum based on normalized isometric maximum in older adults, as shown in figure 4. In figure 4, dotted lines are representative of 95% confidence interval range.

$$NormalizedEccMax = .844 + 1.433(NormalizedIsoMax)$$

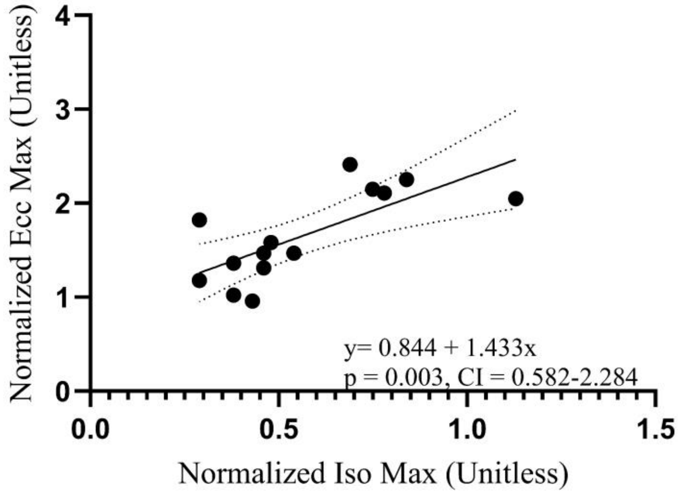

Figure 4. Linear regression of normalized isometric maximum vs normalized eccentric maximum in older adults.

The following equation is the novel regression equation predicting normalized concentric maximum based on normalized isometric maximum in older adults, as shown in figure 5. In figure 5, dotted lines are representative of 95% confidence interval range.

$$NormalizedConMax = .708 + 1.376(NormalizedIsoMax)$$

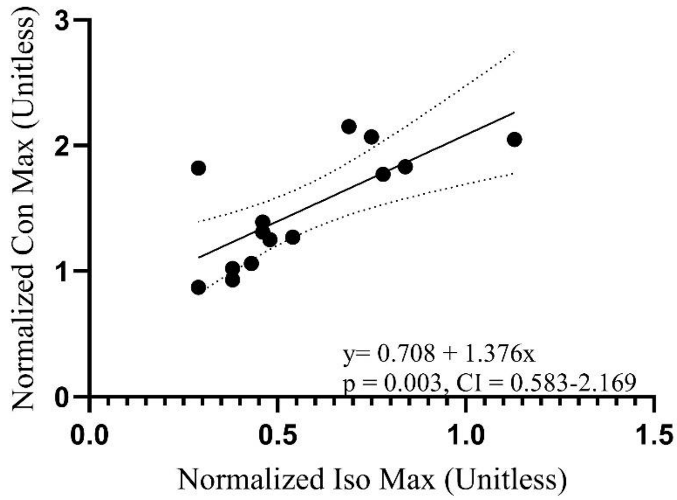

Figure 5. Linear regression of normalized isometric maximum vs normalized concentric maximum in older adults.

The following equation is the novel regression equation predicting normalized eccentric maximum based on PBERM in older adults, as shown in figure 6. In figure 6, dotted lines are representative of 95% confidence interval range.

$$NormalizedEccMax = 0.714 + 0.030(PBERM)$$

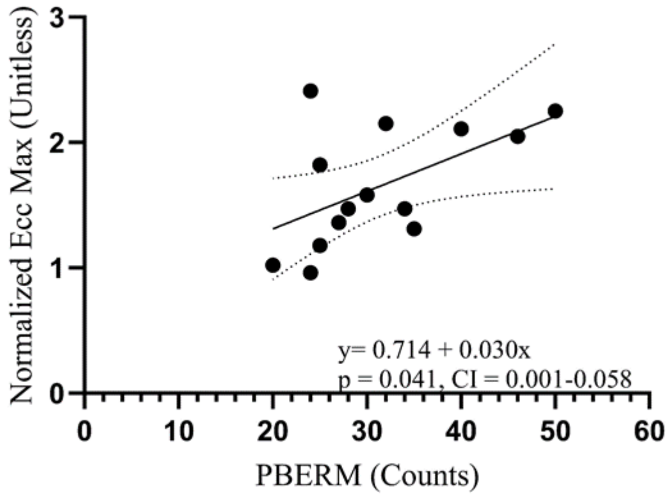

Figure 6. Linear regression of prone back extension repetition maximum vs normalized eccentric maximum in older adults

CHAPTER 4

DISCUSSION

To our knowledge, we are the first to report that the isometric maximum squat strength can predict 1RM concentric and eccentric squat strength in older adults (55-75 years). We also noted that the isometric maximum squat strength was not a predictor of the 1RM eccentric and concentric squat strength values in young adults (21-35 years). Another novel finding of our study was that prone back extension exercise was a significant predictor of 1RM concentric squat strength in young adults and 1RM eccentric squat strength in older adults. The utilization of isometric maximum squat strength and prone back extension exercise to predict 1RM concentric and eccentric squat strength in young and older adults has marked clinical implications. Our findings show that safe techniques for muscle strength assessment, such as isometric maximum squat strength or prone back extension, can be differentially utilized in young and older populations to predict their 1RM of concentric and/or eccentric squat strength, and thus inform effective musculoskeletal rehabilitation programs for the back muscles and the spine.

Multiple factors as discussed below can explain why the maximum isometric squat strength predicted 1RM concentric and eccentric squat strength in older adults only. Older adults do not only show aging-associated deficits in muscle strength of the upper and lower extremity but also alterations in muscle fiber type and motor unit recruitment

(Baum et al, 2009). For example, older vs young adults showed lower values of maximum isometric squat strength and1RM concentric and eccentric squat strength with effect sizes (Cohen’s d) ranging from 0.65-1.5 in our study. It is well-established that as we grow older, aging induces an increase in the proportion of type 1 fibers, while there is a decrease in the relative area of the type 2 fibers (Evans & Lexell, 1995). Thus, we postulate that a combination of loss of muscle strength and fast-twitch Type II muscle fibers may explain the well-known observation of compensatory increase in motor unit recruitment in middle-aged and older adults (Ling et al, 2009). In addition, there is some evidence that motor unit recruitment is consistent to a greater degree in older than young adults (Kirk et al, 2021). Thus, we surmise that low muscle strength, an increased role of Type 1 muscle fibers with all the different types of squats (isometric, concentric, and eccentric) in our study and a consistently high and similar level of motor unit recruitment across different types of squats in older adults can explain why maximum isometric squat strength, 1RM concentric and eccentric squat strength were highly related with each other. It will be interesting to examine if similar findings would hold true for highly physically active older adults or if the findings would hold true in older adults after a resistance training program.

Whereas in young adults, preferential recruitment of Type I vs II muscle fibers to produce maximal strength and the accompanying variable level of motor unit recruitment with different types of squats may explain our non-significant finding of any relationship between maximum isometric squat strength, 1RM concentric and eccentric squat strength (Kay et al, 2000) (Kirk et al, 2021). Moreover, non-concordant relationships between maximum isometric squat strength and 1RM squat strength have been reported before in young athletes (Wagner et al, 2022). Whether young adults with pathological conditions affecting the musculature of the back, such as chronic low back pain, would also show non-significant relationship between maximum isometric squat strength and 1RM concentric and eccentric squat strength is unknown.

Older adults have been found to maintain their eccentric strength with aging, in opposition to concentric and isometric strength that is found to significantly decrease with age (Power et al, 2016) (Roig et al, 2010). This conservation has led to a unique difference in comparing eccentric and isometric muscle strengths between age groups, where older populations demonstrate much higher ratios of eccentric strength to isometric strength than young adults (Power et al, 2015) (Power et al, 2016). Markedly, young adults have lower differences between their eccentric, isometric, and even concentric squat maximums (Power et al, 2016). In our study, 1RM eccentric squat maximum/maximum isometric squat strength and 1RM concentric squat maximum/ maximum isometric squat strength ratios for young adults were 3.3 while they were <3 in older adults. It is unknown if the difference in ratios of the aforementioned squat types could contribute to unique predictive capabilities_of maximum isometric squat strength in older adults.

We were not surprised with our findings of the prone back extension exercise as a predictor of eccentric maximum in older adults, and concentric maximum in young adults. The prone back extension's predictive capabilities for 1RM concentric squat maximum in young adults could be contributed to the concentric contraction of the prone back extension exercise. The prone back extension exercise is performed through concentric contractions of the erector spinae muscle group, and this same muscle group is heavily activated during the partial squat used in the study (Goyal et al, 2013). In fact, both the back extension exercise and the concentric squat have been utilized as means of analyzing the strength of these back muscles and strengthening them (Goyal et al, 2013) (Myles et al, 2014). Thus, the similar contraction of the same muscle group during both the concentric squat and prone back extensions explains the predictive ability of prone back extensions in young adults. However, we did not find a similar result in older adults. The large significant drop in concentric strength, up to 50%, that occurs with age could contribute to the loss of this connection between the two exercises (Roig et al, 2010). Specifically, a large drop in concentric strength with age, in part, could explain why our older adults could not reach as high of a back extension as young adults. We postulate that the time-constraint nature of the prone back extension test combined with the lower degree of back extension in older adults biased the performance of test toward utilizing the eccentric strength of the back muscles, Utilizing the eccentric strength of the back muscles, older adults in our study could perform a quick controlled descent and thus helping to perform maximally for the prone back extension test.

There were limitations to this study that should be noted. Although the sample size for both young and older groups met the necessary power requirements, the sample size was still relatively small. Due to low sample size, we were unable to fully analyze if our prediction equations were affected by sex for each group. Examining if sex could affect our results is important because previous literature has also shown that some of the age-based degradation in muscular contractions is significantly affected by sex, further highlighting the importance of sex and age being analyzed together (Miller, 2013). Future studies should examine if sex can affect the predictive ability of maximum isometric squat for 1RM concentric and eccentric squat strength in young and older adults. The use of the Borg's exertion scale is well supported but also serves as a limitation, as it requires the participant's opinion (William, 2016). Finally, we did not collect data on physical activity to see if that could have affected our results.

CONCLUSION

Overall, the results of our study indicated that isometric squat maximum is a significant predictor of the 1RM of both the eccentric and concentric squats individually in older adults only. The prone back extension exercise repetition maximum predicted 1RM concentric squat strength in young adults, and 1RM eccentric squat strength in older adults.

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APPENDIX: IRB APPROVAL

THE UNIVERSITY OF ALABAMA AT BIRMINGHAM
Office of the Institutional Review Board for Human Use

470 Administration Building
701 20th Street South
Birmingham, AL 35294-0104
205.934.3789 | Fax 205.934.1301 | irb@uab.edu

APPROVAL LETTER

TO: Harshvardhan, Fnu

FROM: University of Alabama at Birmingham Institutional Review Board
Federalwide Assurance # FWA00005960
IORG Registration # IRB00000196 (IRB 01)
IORG Registration # IRB00000726 (IRB 02)
IORG Registration # IRB00012550 (IRB 03)

DATE: 26-Sep-2023

RE: IRB-300004522
IRB-300004522-005
Predicting Maximum Concentric and Eccentric Squat Strength from Maximum Isometric Squat Strength

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The IRB reviewed and approved the Personnel Amendment submitted on 22-Sep-2023 for the above referenced project. The review was conducted in accordance with UAB's Assurance of Compliance approved by the Department of Health and Human Services.

Type of Review:	Expedited
Expedited Categories:	4,
Determination:	Approved
Approval Date:	26-Sep-2023
Expiration Date:	25-Sep-2026

Although annual continuing review is not required for this project, the principal investigator is still responsible for (1) obtaining IRB approval for any modifications before implementing those changes except when necessary to eliminate apparent immediate hazards to the subject, and (2) submitting reportable problems to the IRB. Please see the IRB Guidebook for more information on these topics.