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Comparison of Muscle Force Production Using the Smith Machine and Free Weights for Bench Press and Squat Exercises

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Abstract. Cotterman, M.L., L.A. Darby, and W.A. Skelly. Comparison of muscle force production using the Smith machine and free weights for bench press and squat exercises. *J. Strength Cond. Res. 19(1):169–176. 2005.*—The Smith machine (SM) (vertical motion of bar on fixed path; fixed-form exercise) and free weights (FWs) (free-form path) are commonly used strength training modes. Exercisers may need to alternate between types of equipment, depending on testing, training, rehabilitation, and/or the exercisers' goals. The purposes of this study were to compare muscle force production for SM and FWs using a 1 repetition maximum (1RM) for the parallel back squat and supine bench press exercises and to predict the 1RM for one mode from 1RM on the other mode. Men (n = 16) and women (n = 16) alternately completed 1RM testing for squat and bench press using SM and FWs. Analyses of variance (type of equipment × sex) and linear regression models were calculated. A significant difference was found between bench press and squat 1RMs for each mode of equipment for all participants. The squat 1RM was greater for the SM than the FWs; conversely, the bench 1RM was greater for FWs than the SM. When sex was considered, bench 1RM for FWs was greater than SM for men and women. The squat 1RM was greater for SM than FWs for women only. The 1RM on one mode of equipment was the best predictor of 1RM for the other mode. For both sexes, the equation SM bench 1RM (in kilograms) = −6.76 + 0.95 (FW bench 1RM) can be used. For women only, SM squat 1RM (in kilograms) = 28.3 + 0.73 (FW squat 1RM). These findings provide equations for converting between SM and FW equipment for training.

Key Words. Smith machine, free weights, 1 repetition maximum, squat, bench press, maximal strength performance, strength prediction, exercise, muscle strength, skeletal muscle

Introduction

Resistance training has become one of the most popular forms of exercise for improving physical fitness (13). Dynamic strength is commonly measured by and recorded as the heaviest weight a muscle or muscle group can successfully lift once (i.e., 1 repetition maximum [1RM]) (30) with a proper lifting technique (13). This increased popularity has contributed to a larger market demand for exercise equipment to train for and achieve 1RM. Previous studies have been performed (15, 22, 25, 31) to compare various modes of strength training with different types of equipment (34, 37). More research is needed, because advancements in equipment, training, and rehabilitation techniques continue to occur.

The most commonly used types of strength training equipment are free weights (FWs) and machine weight modes. These can be defined as free-form and fixed-form exercises (3). Free-form exercises allow for movement in multiple planes and require balance. Fixed-form exercises maintain the pattern movement over a range of motion (3). A machine exercise may replace a FW exercise or vice versa. Substitutions may occur based on testing requirements, training needs, rehabilitation, or the ability of the lifter. Equating workloads between modes may be rather difficult and sometimes impossible to achieve (33). For this reason, the relationship between similar exercises performed on different types of equipment must be examined and a method for determining equivalent workloads needs to be established.

Free weights can be used for a variety of different exercises and muscle groups, the load can be readily determined and varied, and the movement of the bar or dumbbell is not externally controlled by a machine (40). Muscle contractions while using FWs allow for and are more similar to natural movements, because the exercise is rarely performed at a constant velocity through the range of motion and requires balance in all planes (33).

The Smith machine (SM) is a type of strength training and testing mode often found in health clubs, recreation centers, and sports medicine rehabilitation clinics. The SM uses an Olympic-sized bar and FW plates much like a FW Olympic bar and plates. The bar is attached on both ends to either a vertical steel bar that acts as a guide rod on which the bar slides up and down or a straight lever arm that attaches to a pivot joint on either side of the machine. In both cases, the vertical motion of the bar remains on a fixed path, restricting the movement of the lifter (i.e., fixed-form exercise). The decreased need for balance of the bar and weight plates may increase the safety of using this type of strength training mode. Additional safety may be afforded in the system through the safety lockouts provided every few inches throughout the entire range of motion of the bar. Attached to the bar are hooks that, with a slight wrist rotation, will latch onto the safety lockouts located on the frame of the machine. The increase in safety and the multiple exercises options (i.e., bench press, shoulder press, shrugs, upright row, squat) increase the popularity of the SM as a resistance exercise mode.

To date, no previously published research has compared the SM with another resistance machine or FWs during exercise. The fixed vertical bar path on the SM may cause alterations in lifting technique, muscle group recruitment, and force production when compared with similar FW exercises. When performing squatting techniques on the SM, the performer can slightly lean against the bar throughout the range of motion. This leaning action results from a slightly forward foot placement in front of the fixed vertical motion to keep the knees behind the toes and over the ankles. This recommended limb alignment is the same for the FW squat (29). When compared with the FW squat, the SM squat requires less balance of an external load, which may allow for a greater load to be lifted.

The major difference in the bench press on the SM and FWs is the fixed horizontal bar path of the SM throughout the range of motion. The FW bar path for the bench press may have an S pattern or horizontal displacement toward the shoulders (reverse C pattern) during the ascent (33). Without a horizontal movement of the bar, SM bench press loads may decrease due to a change in bench press mechanics. When compared with the FW bench press, the fixed vertical motion of the SM bar may not allow the upper body to effectively use the muscles normally required for a FW bench press, which might in turn cause less weight to be lifted on the SM bench press exercise.

Although the type of equipment may affect force production, several other factors can affect the measurement of muscular strength, including neuromuscular control, muscle fiber type, muscle size, sarcomere length, angle of muscle pull, the force-velocity relationship, elastic potential of muscle, and neuromuscular inhibition (40). Lifter proficiency (24, 26) and body composition (16, 17) also affect lifting performance. Each factor, or combination of these factors, directly affects the body's ability to create enough force to overcome an external load. In addition, sex differences may affect physical performance and are influenced by variations in body size, body composition, aerobic power, and muscular strength (38). Body size differences are most often apparent in the upper torso or upper body of men and women (5, 16, 28, 39). However, measurement of muscle tissue in women, unit for unit, does not differ in potential force output from men's muscle tissue (18).

Therefore, the primary purpose of this study was to examine force production on the SM and FWs using similar exercises. The secondary purpose of this study was to develop regression equations to predict 1RM performance on each mode (SM and FWs) of testing from one or more independent variables. This information may allow strength and conditioning coaches and health and fitness professionals to more effectively use the SM and FW exercises for training and testing and to increase sports performance.

Methods

Experimental Approach to the Problem

To test the hypothesis that there is a significant difference in 1RM due to type of equipment, a repeated-measures design was used. For each exercise (i.e., squat and bench press), the 1RM from one type of equipment (i.e., FWs) was compared with the other type (i.e., SM). It was hypothesized that the 1RM measured using the fixed vertical path of the SM (fixed form) would be different from the 1RM measured using the FWs (free form; balance of the weight on bar necessary in all directions) for squat and bench press lifts.

Subjects

Men and women 18–25 years of age volunteered for the study. Each participant was classified as low risk (1) based on responses to a medical history questionnaire, and no physical limitations or musculoskeletal problems that would affect physical training or testing were reported. Each participant gave written, informed consent before testing and completed a strength training history questionnaire. The strength training history questionnaire was used to assess each participant's past and current strength training practices, including frequency, intensity, and type of equipment.

Equipment

Testing for bench press and parallel squat was completed using FWs and a fixed vertical plane SM (Promaxima, Inc., Houston, TX). The FW parallel squat was performed on a power rack (Fitness Systems, Inc., Hazel Park, MI), whereas the FW bench press was performed on a flat bench and rack (Custom Weight Rooms, Inc., Hastings, MI). Olympic weights and an Olympic-sized bar were used for all strength testing.

Testing Procedures

Each participant attended 3 sessions: an orientation and demographic data collection session and two 1RM testing sessions. In the first session, participants were oriented to the SM and FW modes. Demographic data were collected, which included the participant's height, weight, body composition, limb and body girths, limb, and trunk length measurements. Instructions regarding preparation for the 1RM testing sessions and proper form and lifting technique for the parallel squat and supine bench press exercises were distributed to each participant to control pretest activities and standardize test preparation.

Each participant performed 2 sets of 10 repetitions to acclimatize to the exercises and to standardize hand grip and foot spacing for the bench press and squat, respectively. For each exercise (i.e., bench and squat), during the first set of 10 repetitions, the depth of the movement was set, and during the second set of 10 repetitions, hand spacing and foot spacing were set. Hand spacing was set on the bench press at 165–200% of bisacromial width, which has been shown to provide the highest strength values of all grip widths for the supine bench press (36). This spacing placed the elbow at a desired 90° angle and a trunk-to-upper-arm angle of nearly 90° during the final phase of the ascent. This technique allows for optimal use of the pectoralis major while still allowing the triceps to add to initial explosiveness (7). Foot spacing on the squat was set at approximately the same width as, or slightly wider than, shoulder width with toes pointed slightly outward (4). Hand and foot spacing were recorded for replication in subsequent 1RM tests.

After spacings were set, each participant performed a 5 repetitions maximum (5RM) test to determine an estimated 1RM. The purpose of predicting a 1RM was to minimize fatigue in subsequent 1RM tests. For the warm-up, each participant performed 2 sets of 10 repetitions for the required pretest settings and then performed 1 set of 10 and 1 set of 6 repetitions at their individually chosen weight. After warming up, participants chose a weight they could lift a minimum of 3 times without exceeding 7 repetitions, later performing the exercise at the given resistance. This procedure was applied for both the squat and bench press exercises. Once the participant completed the 3 and 7 repetitions to failure, a formula was used to estimate 1RM based on the number of repetitions completed at that weight (12).

The first participant for each sex was randomly assigned to either the FW or SM modes for the testing. The subsequent participants for each sex began on the other type of strength training equipment to counterbalance the order of presentation. After warm-up, 1RM was determined for each participant using the squat and then bench press exercises for each strength training mode. The warm-up consisted of 5 minutes of stationary cycling at 60 rpm and 1.5 kg of resistance, stretching exercises, and 1 set of 10 repetitions with light weight on each exercise.

The 1RM procedures as outlined by Stone and O'Bryant (33) were performed by each participant: (a) warm-up of 50% of approximately 1RM for 8–10 repetitions; (b) 1 minute of rest and light stretching and a second set of 75% of approximately 1RM lifted for 3–5 repetitions; and (c) after 2–3 minutes of rest and more light stretching, 3–4 1RM attempts performed with 2 minutes of rest between each attempt. After each repetition, the weight was increased by 2.5–10 kg for each repetition until failure. The final weight lifted was the 1RM. The recovery times between 1RM attempts was approximately 2–3 minutes. The same procedures were completed for 1RM testing for bench press and squat exercise on each type of equipment with no less than 2 and no more than 6 days elapsed from the previous 1RM test.

Testing began for the FW bench press when hand spacing was marked on the bar and instructions for proper performance were repeated. Participants were required to keep their backs on the bench and feet on the floor during the entire test. When the participant received assistance in lifting the bar from the rack, the bar was held briefly with straight arms until a signal was given to proceed and the bar was then lowered to the chest. Once the bar was motionless on the chest, the spotter gave a signal to vertically press the bar up to straight-arm length. No assistance was given to keep the bar moving during the ascent phase unless failure occurred. The SM bench press was performed in the same manner as the FW bench press. The spotter assisted the participant with lifting and rotating the bar into the initial position. Safety catches were placed just below chest height.

All FW squat tests were performed using a power rack for safety. In case of a failed lift, the power rack allowed the participant to drop the weight straight down and/or forward so the rack could catch the bar without causing injury to the participant. Safety bars were placed just below 90° hip flexion for increased safety and as a visual marker for the lifter to attain proper squat depth. The foot spacing was set, and the appropriate weight was added. The participant was instructed on the procedures and allowed to start. The participant slowly lowered the bar while keeping the torso erect and back straight with the bar resting on the shoulders just below the seventh cervical vertebra. The descent stopped when the posterior borders of the hamstring muscles were parallel with the floor. To ensure proper squat depth on each attempt, a thin, non–weight-bearing, rubber therapy band was tied to the squat rack. After reaching the appropriate depth, the participant vertically raised the weight as they assumed a straight leg position.

Table 1. Demographic data of subjects (N = 32).*

Variable	Mean (*SD*)
Age (y)	22 (2)
Height (cm)	177.5 (10.9)
Weight (kg)	81.9 (20.9)
Body fat (%)	18.4 (5.1)
Bench SM (kg)	67.4 (36.3)
Bench FW (kg)	78.3 (38.0)
Squat SM (kg)	129.0 (50.6)
Squat FM (kg)	124.3 (51.3)

* SM = Smith machine (1 repetition maximum); FW = free weights (1 repetition maximum).

The SM parallel squat was performed in the same manner as the FW parallel squat. Safety latches were positioned just below parallel to catch the bar in the case of a failed attempt. Foot stance width was self-selected, except the participant's heels were required to be within a 6-in. area in front of the machine. This consisted of an area from the vertical guide rods to 6 in. in front of the machine.

Body density (D_b) and percentage of body fat were predicted using skinfold measurements of specified sites according to sex (17). Body girths, segmental lengths, and body breadth were also measured at various sites for each participant. D_b was estimated by using the skinfold equations of Jackson et al. (19, 20) for men and women. D_b was converted to percentage of body fat using the Siri equation (32).

Statistical Analyses

Two 2-way (between, within) analyses of variance were calculated to determine the effects of the independent variables sex and type of equipment on the dependent variables (i.e., 1RM for the squat and bench press). If a significant difference occurred between the types of resistance modes, then forward and backward stepwise multiple linear regressions were calculated.

A priori analysis with G*Power (6) was used to determine a sample size of 32 using a power of 0.58 with a large effect size (ES) of 0.40 ($p \leq 0.05$). A posteriori practical significance was evaluated using the F value to describe the ES, each specific within comparison (8). Practical significance is defined as a difference that is "large enough to be significant in the real world" (21). Effect size is defined as a difference between means expressed in *SD* units (21). A large practical significance would be F = 0.40, 0.25 for medium significance, and 0.10 for a small practical significance (6, 8).

Means and *SD*s were calculated for all dependent variables. One-way (response) and 2-way (response × sex) χ^2 statistics were calculated to determine differences in responses and sex to the strength training history questionnaire (21).

Results

Descriptive Statistics

Demographic data for the participants (N = 32) are presented in Table 1. All participants self-reported at least 1 year of strength training experience. Most participants reported at least 2 years of squat (21 [66%] of 32 partic-

Table 2. Mean and *SD*s of 1 repetition maximum performance (N = 32; 16 men and 16 women).*

	Mean ± *SD*		Mean			
	SM	FW	difference†	p	F‡	$1 - \beta$§
Squat						
Men	171.5 ± 35.7	168.2 ± 32.2	3.28	0.1857	0.37	0.71
Women	86.6 ± 13.8	80.4 ± 17.2	6.25	0.0049¶	0.81	0.61
Total‖	129.0 ± 50.6	124.3 ± 51.3	4.77	0.0036¶	0.55	0.60
Bench						
Mean	100.6 ± 17.6	112.9 ± 18.8	−12.34	<0.0001¶	2.09	1.00
Women	34.2 ± 8.3	43.7 ± 9.2	−9.51	<0.0001¶	3.26	1.00
Total‖	67.4 ± 36.3	78.3 ± 38.0	−10.93	<0.0001¶	2.31	1.00

* SM = Smith machine; FW = free weights.
† Smith machine minus free weights.
‡ Practical significance.
§ Power.
¶ Main effect for type of equipment.
‖ Main effect for sex.

ipants; nonsignificant $\chi^2 = 3.16$, $df = 1$, $p < 0.05$) and bench press (26 [81%] of 32; significant $\chi^2 = 12.53$, $df = 1$, $p < 0.05$) experience. Specifically, when experience on each type of equipment was assessed, 20 (63%) of 32 participants (nonsignificant $\chi^2 = 2.03$, $df = 1$) had never used the SM for squat exercise. Twenty-three (72%) of 32 (significant $\chi^2 = 5.28$, $df = 1$, $p < 0.05$) had never used the SM for bench exercises. Most participants had FW squat (28 [88%] of 32) and FW bench (31 [97%] of 32) experience. When sex and experience were assessed, the proportion of men with squat experience was greater than women (significant $\chi^2 = 4.99$, $df = 1$, $p < 0.05$). There was no association between sex and frequency of bench press experience (nonsignificant $\chi^2 = 2.93$, $df = 1$, $p < 0.05$).

Comparison of Strength Training Modes: SM vs. FWs

There was a statistically significant difference ($p = 0.0036$) between the modes of training for the squat exercise ($N = 32$) (Table 2). The SM mean squat 1RM was 4.77 kg greater than the FW mean squat 1RM (Table 2). When the F value was calculated to test practical significance, the ES of 0.55 was large and indicated practical significance. For the supine bench press exercise, a statistically significant difference ($p \leq 0.0001$) was found between the FW and SM 1RM ($N = 32$). In contrast to the squat exercise, the FW mean was 10.93 kg greater than the SM mean for this bench press exercise (Table 2). Between the FW and SM bench, a large ES of 2.31 was calculated and indicated practical significance. All participants performed a greater 1RM for the FW bench press compared with the SM, and 16 of the 32 participants performed a greater SM squat compared with FW. Of the remaining 16 participants, 5 performed a 1RM on the SM squat to within 5 kg of the FW squat, and 3 participants performed a greater 1RM FW squat.

For women only, there was a statistically significant difference ($p = 0.0049$) between the SM and FW squat exercises, with SM squat a mean of 6.25 kg greater than the FW mean (Table 2). An ES of 0.81 was calculated for these squat results and is considered large. A statistically significant difference ($p \leq 0.0001$) was also found between the women's FW and SM bench press exercises, with a FW bench mean of 9.51 kg greater than SM and an ES of 3.26 (Table 2).

For men only, there was no significant difference ($p = 0.1857$) between the FW and SM for the squat exercise. A medium ES of 0.37 existed between the SM and FW squat exercises. For the bench press exercise, there were statistical ($p \leq 0.0001$) and practical significant differences (ES = 2.09) between the FW and SM, with a mean FW of 12.34 kg greater than the SM (Table 2).

Prediction of 1RM Mode to Mode

Since no statistically significant difference was observed between the modes for the squat for men, a squat regression equation was only developed for women. Selected variables for each exercise (i.e., squat and bench) were used in stepwise linear regressions to determine the variables that explained the most variance to predict 1RM. Again, 1RM from each mode explained the greatest percentage of variance for the 1RM on the other mode. Therefore, the equation to predict SM 1RM for women is as follows:

$$\text{SM 1RM (in kilograms)} = 28.3 + 0.73\ (\text{FW squat})$$

$$SEE = 5.9\ \text{kg (women only)}$$

For the bench press, the independent variables of sex, upper arm cross-sectional area, chest circumference, upper arm circumference, and the 1RM on the previous mode were entered for the regression. In Table 3, the means, *SD*s, and R^2 for the variable used in the bench press regression equations are given. For each mode (i.e., SM and FW), the variable with the greatest proportion of the total variance, adjusted R^2, was the 1RM for the previous mode. For the SM bench press, the previous FW bench press 1RM ($R^2 = 0.9847$) was the best variable to use in the regression equation to predict SM bench press 1RM (Figure 1). Regression equations for each sex were not computed to maximize the number of participants used in the regression (35). The equation was as follows:

$$\text{SM bench (in kilograms)} = -6.76 + 0.95\ (\text{FW bench})$$

$$SEE = 4.6\ \text{kg}$$

Sex Comparisons Regardless of Mode

When the data were combined regardless of mode and divided by sex, a statistically significant difference was

TABLE 3. Means, *SD*s, and R^2 for Regression Equation Variables ($N = 32$).

Variable	Mean ± *SD*	R^2 SM*	*p*	R^2 FW†	*p*
Bench press		0.9847	0.0001	0.9847	0.0001
Sex		—‡	0.2023	—	0.7661
Arm cross-sectional area (cm) ($n = 31$)	57.9 ± 22.2	—	0.2906	—	0.8960
Chest circumference (cm)	98.9 ± 10.0	—	0.4942	—	0.7297
Upper arm circumference (cm)	32.0 ± 5.2	—	0.3565	—	0.9066

* R^2 for the regression equation for estimating the 1 repetition maximum (1RM) Smith machine (SM) from the 1RM free weight (FW).
† R^2 for the regression equation for estimating the 1RM SM from the 1RM FW.
‡ Did not meet 0.15 *F* criterion level for entry into the model (SAS default).

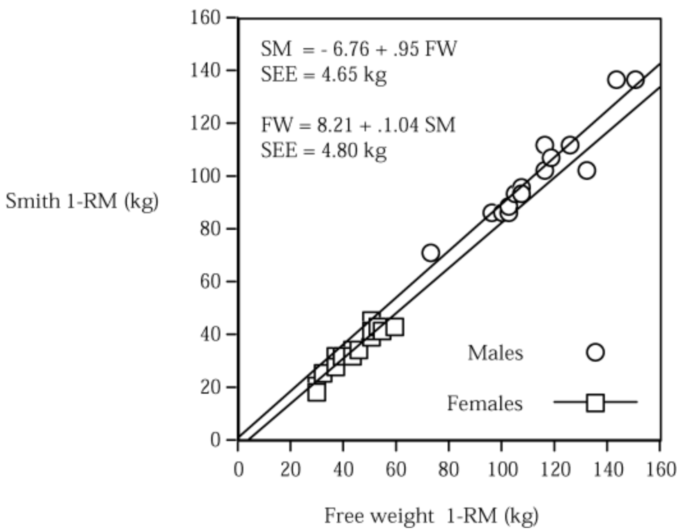

FIGURE 1. Regression for the Smith machine (SM) and free weight (FW) 1 repetition maximum (1RM) for bench press.

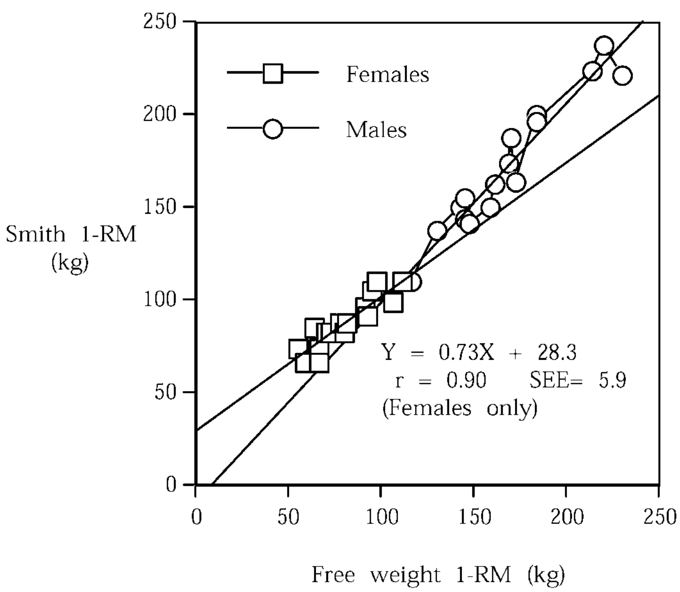

FIGURE 2. Regression for the Smith machine (SM) and free weight (FW) 1 repetition maximum (1RM) for squat exercise.

found for sex and 1RM strength ($p \leq 0.0001$) for both the squat (Figure 2) and the bench press (Figure 1). The mean ± *SD* 1RM for men for the bench press was 106.8 ± 19.0 kg, whereas for women the mean ± *SD* was 39.0 ± 9.9 kg. For the squat, the mean ± *SD* 1RM for men was 169.9 ± 33.5 kg, whereas the mean ± *SD* for women was 83.5 ± 15.7 kg. Unpaired *t*-tests, comparing anthropometric measurements by sex, were used to determine if a significant difference existed between the sexes. All variables were statistically significantly different ($p < 0.05$) between the sexes except for body fat percentage ($p = 0.075$).

DISCUSSION

Based on previous findings (2, 10, 26, 27), it was believed that a reduced need for balance would create a greater SM squat, since less muscle activity is being used toward balance. It was also hypothesized that the increased trunk to thigh angle observed during the SM squat would mimic the performances of skilled FW performers (10, 26, 27) and would increase the load that could be lifted on the SM. There was a significant difference in SM and FW squat 1RMs when all participants were included in the analysis. However, when divided by sex, only women had a significantly greater SM 1RM for squat. This finding may indicate that the variables mentioned herein may not have enhanced SM squat performance. Future studies may control for or specifically measure these variables to determine why SM and FW 1RMs are different in some individuals and not in others.

The similarities between the SM and FW squats may best explain why no significance was found between the modes for men. The multijoint movement of the squat motion may be similar enough between the modes so a difference would not be observed for muscle force production. However, to test this hypothesis, a kinematic analysis on the SM and FW squat motions should be performed but was beyond the scope of the present study. A future kinematic study could focus on joint angles and speeds, with emphasis on the thigh (26) and trunk angle as key variables that may affect squat performance. Analyses may also need to be performed that examine the depth of the squat and how depth affects the squat force production for each mode.

If the men's and women's performances are examined independently, the conclusion of no practical significance does not hold true. The women participants displayed practically significant (i.e., a difference large enough to be meaningful and applicable in the real world) and statistically significant differences between the SM squat and FW squat. In contrast, the men did not show practical or statistically significant differences in the amount of weight lifted during the squat. The men had a 3.3-kg mean difference between the modes for the squat, whereas the women had a 6.3-kg mean difference. The wide range of FW squatting experience reported by the men may explain the greater variance in the men's sample.

Those men with more FW squat experience, especially current experience with heavy weights, displayed a lower SM squat than those with less squat experience. The explanation for this may be associated with the muscle demands of each mode of squatting. During a FW squat, the hips are pushed backward as if to sit in a chair, which allows the knees to have a minimal horizontal travel toward the toes (23, 29). This limits the shear forces on the knees and allows for more weight to be carried by the pelvic girdle, hamstrings, and gluteus muscles (29). Andrews et al. (2) have indicated that more force and more knee shear were present when the squat was performed using a Universal machine that when using FWs. However, the weight was placed in front of the lifter rather than behind the lifter as in the present study. If the knee can remain in a more vertical position during the SM squat, then shear forces can be reduced at the knee. However, when performing a SM squat in a fixed vertical plane, the feet must be slightly in front of the bar path to lessen the horizontal knee travel and reduce stress placed on the knees. Basically, the performer must lean slightly backward against the bar, and, when squatting in this position, more stress may be placed on the thigh than would be experienced during a FW squat. Therefore, those participants who have been engaging in heavy FW squats for an extended period would have developed strong gluteus and hamstring muscles. These muscles may be more developed than the quadriceps region, which may experience more use during the SM squat. This would help explain why those with less experience performing the squat had a greater SM squat 1RM. Future studies may further study differences in foot placement, force production, and knee shear forces.

Finally, a small number of participants self-reported an “awkwardness” when performing the SM squat and attributed this lower 1RM on the SM mode during the squat to their uneasy feeling. This is to be expected when 63% of participants stated they had no previous experience on the SM squat before this study. The participants were allowed several practice sets before a 1RM measurement was taken. In general, (a) those with more FW squat experience were able to lift more on FWs; (b) those with moderate experience with the FW squat (4–7 years) performed about the same on both modes or slightly better on the SM; and (c) those with less experience generally performed better on the SM.

Although the purpose of this study was to examine the effect each mode of equipment had on muscle force production, several biomechanical factors observed during this present study may be studied in future biomechanical research and may contribute to the differences found in the present study. All participants were required to achieve a depth where the posterior borders of the thighs were parallel to the ground. A 4-in. wide rubber band was placed across the squat rack to mark the proper depth. When this depth is held constant for each type of equipment and test, as it was for this study, the depth of the squat plays an integral part in the 1RM performance. Lifters should be able to perform a half squat with more weight than they would be able to perform a full squat (10, 27). This preset depth became the limiting factor on the amount of weight a performer could lift. If a participant performed a 1RM squat to parallel and failed and then the depth of the squat was raised slightly, an increased chance of a successful lift could occur. Lander et al. (22) explained the sticking region as the region of the applied force-time curve where failure is most likely to occur if the initial impulse during acceleration or applied strength in the midrange is insufficient. If the lifter never squats down far enough to pass through a sticking region (i.e., less than parallel), then more weight can be lifted because the sticking region is avoided. McLaughlin et al. (26) found the sticking region to be at a thigh angle of $29.6° \pm 2.0°$ from horizontal.

When performing a SM squat, the back muscles may be placed under less stress than during a FW squat. The forward trunk lean is greater during a FW squat and increases in many less skilled performers as depth of the squat increases. This is especially true of performers with less experience performing the squat exercise, because they may have not developed the lower back muscles needed for stabilization. McLaughlin et al. (27) found that the less skilled the lifter, the more forward trunk lean the lifter experienced. DiNubile (9) found that the sticking point was caused by increased trunk lean during the initial part of the ascent phase. In essence, a performer may be able to squat to a lower depth with more weight during a SM squat than during a FW squat. This may explain why participants in the present study lifted a greater squat weight with SM than with FW.

The width of foot stance was also a mode-specific factor that affected performance. Foot stance width was established during the first session of testing and was held constant throughout all tests. Participants self-selected their foot stance during the 5RM testing session when completing lifts on the first mode. This was a problem for those initially tested on the SM. Participants who self-selected a stance width that was comfortable for the SM mode of testing later discovered the stance was too narrow for the FW squat. This dilemma was especially true of individuals with high to moderate FW squat experience. Some participants were more comfortable and had a wider stance when tested first on the FW squat. These discrepancies in foot placement for each mode were observed in only a few participants and were subjectively determined to be too small to affect the individual performance of the exercise.

The FW bench press was significantly greater (16%) than the SM bench press exercise. The proposed rationale for this difference between the modes may be explained by the path of the bar during the ascent. Madsen and McLaughlin (24) established 5 kinematic factors that affect the bench press: (a) a “sticking point” during the movement, (b) the position of the bar path relative to the shoulders, (c) the sequence in bar movements when raising the bar, (d) handgrip spacing, and (e) the degree of control maintained when lowering the bar. During this present study, hand grip width was controlled, the control of the descent and sticking point were determined by the individual performer, and the bar path and movement sequence were either determined by the performer or controlled by the mode of testing. The SM, with its fixed vertical guided motion, did not allow for the normal curve the bar path usually takes during the FW bench press. This curve is either an S pattern or a pattern much like a reverse C, where the bar is horizontally displaced toward the shoulders (33). This restricted movement limits the muscle use of the upper body and, therefore, limits the force produced during the SM bench press exercise.

Previous studies have shown that the bar path can affect the performance of the load being lifted (11, 24). Madsen and McLaughlin's (24) kinematic study found that the bar path for novice lifters was significantly further from the shoulders in both the descent and ascent phases of the bench press. This bar path position resulted in less weight being lifted (novice = 101.5 kg; expert = 185.0 kg) and simulates what happens to a performer during the SM bench press. During a SM bench, the bar must come down and touch the middle of the chest as it would during the FW bench press; however, during a SM bench, the bar will finish above the middle of the chest when the arms are fully extended, not closer to the shoulders due to the guided vertical motion. Therefore, all performers are essentially "forced" to follow a novice bar path during the SM bench and force production may be reduced.

All participants in this study demonstrated a greater FW 1RM bench press than SM bench press. Inexperience may have attributed to the difference between modes, because 72% of the participants have never used the SM for the bench press exercise, whereas 97% of the participants had previously used the FW bench press. The men showed a greater mean difference between bench press modes (12.3 kg) than the women (9.5 kg). This may be due in part to the difference between the sexes in upper body size and strength. Sex differences in physical performance are in large part due to the variations in body size, body composition, aerobic power, and muscular strength (38). This is evident in this study, because the women's mean height was 15.2 cm shorter, mean weight was 31.7 kg less, and mean body fat percentage was 3.2% greater than the men's. This study, along with other studies (5, 16, 28, 39), found that the greatest difference in strength between the sexes is in the upper body.

There was a significant difference between the SM and FW modes for the supine bench press exercise 1RM. Therefore, regression equations to predict the 1RM for one mode from a 1RM measurement using the previous mode were developed. Multiple stepwise regressions were used to predict the lifting performance on one mode by using variables that may have a direct relationship to the exercise being predicted. Predictor variables were placed into the model to evaluate their relationship with the criterion variable (i.e., 1RM for the SM bench or 1RM for the FW bench). Each time a new predictor variable was added, the new relationship between the variables and the criterion is reevaluated to ensure that the preselected variables still significantly contribute to the prediction equation (35). The variables with the greatest amount of explained variance, or largest R^2, will significantly contribute to the prediction equation.

For the bench press exercise, chest circumference, arm cross-sectional area, upper arm circumference, sex, and the 1RM on the previous mode were placed into the regression equation. The 1RM on the previous mode of testing proved the best variable to place in the regression equation regardless of sex and eliminates the need for a sex-specific equation. The other 4 variables did not significantly explain the proportion of variance of the criterion variable. The estimated regression equations for the FW and SM bench press are shown in Figure 1.

Based on the results of this study, a difference existed between the SM and FW modes using the bench press exercise. The difference in weight lifted on each mode can be determined by using a regression equation that consists of the 1RM previously attained on the opposite mode and the intercept and slope of the regression line. These equations allow for transpositional use of the SM and FW modes by estimating similar workloads between the modes of training and testing. Hence, if a performer knows his or her FW bench is 125 kg then that variable can be placed into the equation SM bench (in kilograms) = 6.76 + 0.095 (125 kg), to determine his or her SM bench.

Friction is present in all strength training machines where 2 surfaces come into contact in any pulley, cam, lever arm, pivot joint, cable, piston, or guide rod. "Friction is a force acting parallel to the interface of two surfaces that are in contact during the motion or impeding motion of one surface as it moves over the other" (14). For the SM in this study, the cable winding through the pulleys, the bearings on which the pulleys spin, or, more specific to this machine, the encased bearings that slide on the vertical guide rods all may cause friction in the system.

Dynamic or kinetic friction could not be accurately measured during this study because of the need for sophisticated equipment. An attempt was made to determine the static friction present in the system; however, the researcher determined that this varied, depending on the vertical height of the bar on the guide rods. Further, if all participants overcame the static friction of the machine, then it is dynamic friction that should be measured. Hamill and Knutzen (14) state that dynamic friction is less than maximum static friction and is approximately constant for the speeds experienced in this study. To estimate the effect of friction on the results, dynamic friction was estimated by hanging enough weight from the bar so that the bar would not stop as a result of friction in the system during a descent. The amount of dynamic friction was measured in the system as it existed after the last data collection and measured again with silicon spray lubricant added as was performed at the beginning of the study before data collection. It was estimated that the friction accounted for 1.1 kg (lubricated guide rods) to 1.4 kg (unlubricated) of the weight lifted by the participants on any exercise. As friction increases within the system, the more likely the results may be affected. As friction increases, a significant difference may be observed with the squat results; however, the bench press significant difference would increase. For the bench press, the difference between the modes is great enough to expect that friction had no effect on the significant difference between the loads lifted on each mode. The researcher concluded that the guided motion of the SM better represented the difference in the force production of the modes. Further, the amount of friction on each SM will differ, and it is not practical to measure the friction on each machine and include the difference in the measurements of the performer. Determining friction in the field may not be precise enough to measure the appropriate amount of frictional force. Further, when applied to the performance of the lifter, the friction may be too minimal to affect results.

PRACTICAL APPLICATIONS

In the present study, a significant difference existed between the SM and FW modes using the supine bench press exercise. Due to the difference in weight lifted between the modes for supine bench press, a regression equation was developed to determine equal workloads between each mode for both sexes. The 1RM on the previous mode was found to be the best predictor to estimate 1RM on the opposite mode regardless of sex. The back squat exercise was found to be statistically significantly different between the SM and FW modes. However, since the ES was small for men, this difference between the modes for the squat was not practically significant. For women, the power and ES were acceptable; therefore, a regression equation to predict 1RM for one mode to the other was determined. These findings should provide valuable information for individuals who intend to use the SM in conjunction with FWs for increasing muscular strength.

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