THE USE OF THE ISOMETRIC SQUAT AS A MEASURE OF STRENGTH AND EXPLOSIVENESS

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ABSTRACT

Bazyler, CD, Beckham, GK, and Sato, K. The use of the isometric squat as a measure of strength and explosiveness. *J Strength Cond Res* 29(5): 1386–1392, 2015—The isometric squat has been used to detect changes in kinetic variables as a result of training; however, controversy exists in its application to dynamic multijoint tasks. Thus, the purpose of this study was to further examine the relationship between isometric squat kinetic variables and isoinertial strength measures. Subjects (17 men, 1-repetition maximum [1RM]: 148.2 ± 23.4 kg) performed squats 2 $\text{d}\cdot\text{wk}^{-1}$ for 12 weeks and were tested on 1RM squat, 1RM partial squat, and isometric squat at 90° and 120° of knee flexion. Test-retest reliability was very good for all isometric measures (intraclass correlation coefficients > 0.90); however, rate of force development 250 milliseconds at 90° and 120° seemed to have a higher systematic error (relative technical error of measurement = 8.12%, 9.44%). Pearson product-moment correlations indicated strong relationships between isometric peak force at 90° (IPF 90°) and 1RM squat ($r = 0.86$), and IPF 120° and 1RM partial squat ($r = 0.79$). Impulse 250 milliseconds (IMP) at 90° and 120° exhibited moderate to strong correlations with 1RM squat ($r = 0.70, 0.58$) and partial squat ($r = 0.73, 0.62$), respectively. Rate of force development at 90° and 120° exhibited weak to moderate correlations with 1RM squat ($r = 0.55, 0.43$) and partial squat ($r = 0.32, 0.42$), respectively. These findings demonstrate a degree of joint angle specificity to dynamic tasks for rapid and peak isometric force production. In conclusion, an isometric squat performed at 90° and 120° is a reliable testing measure that can provide a strong indication of changes in strength and explosiveness during training.

KEY WORDS reliability, rate of force development, peak force, specificity

INTRODUCTION

The isometric squat performed on a force platform has been used as a means of detecting changes in kinetic variables as a result of training (20,27,38–40). Previous research has established that the isometric squat is strongly related to performance on the 1-repetition maximum (1RM) barbell back squat (6,8,28). In the past, the use of isometric tests to assess changes in dynamic performance was considered suboptimal, primarily because of the neural and mechanical differences between isometric and dynamic muscular actions (1,25,36). These problems have been addressed recently with multijoint isometric assessments, in which tasks are closed chain, and at specific joint angles to maximize force (10,20,28,29). Although it is evident that isoinertial tests (e.g., 1RM back squat, 1RM power clean) and field tests (e.g., 10-m sprint, repeat agility tests, standing long jump, and overhead shot throw) demonstrate greater external validity in their ability to monitor changes in dynamic movements (12,13,36), there are limitations to isoinertial and field tests that can be overcome by multijoint isometric testing (38). For example, shot putters may improve their overhead shot throw performance; however, this does not indicate which specific strength qualities (maximal strength, rate of force development [RFD], and time to peak force) have improved. Thus, multijoint isometric tests, such as the isometric squat, can be used to complement and augment isoinertial and field-based testing results.

For an isometric test to correspond to a dynamic movement, there must be a high degree of task specificity with factors such as body position, joint angles, and kinetic similarity (17,26). Therefore, joint angles of the isometric test should correspond to the joint angles in the dynamic movement, joint angles of the isometric test should correspond to the joint angles in the dynamic movement in which force output is the highest (~120° knee angle for the back squat) (18,26). Another important consideration is the position in the lift when mechanical advantage is at the lowest, specifically the "sticking region" in the squat task (~90° knee angle for the back squat) (2,24). Blazevich et al. (6) found that isometric squats performed at 90° of knee flexion are highly correlated ($r = 0.77$) with 1RM squats performed to a depth of 90° knee flexion. As such, previous research has examined the isometric squat using angles of 90° (6,8,27) and

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120° (20,38,40), although other knee joint angles have been used (28,29,37,39). Thus, an isometric squat performed at 90° and 120° should provide a strong indication of the 1RM back squat and changes in strength in the lower extremities after a training program that includes squats. Importantly, isometric testing is relatively easier to standardize than dynamic testing, which should provide improve reliability and subsequently the ability to detect changes over time.

Therefore, the purpose of this study was to further explore the use of the isometric squat as a measure of strength and explosiveness for training studies. Specifically, this study elaborates on the relationship between kinetic variables from the isometric squat and isoinertial performance measures and considers practical applications for its use as a testing measure. It was hypothesized that the isometric squat would be a reliable measure of strength and explosiveness in the sample tested, correlations between dynamic and isometric measures would be joint angle specific, and isometric measures of maximal strength would be more strongly related to 1RM results than to isometric measures of explosiveness.

METHODS

Experimental Approach to the Problem

Subjects performed squats 2 $d \cdot w^{-1}$ for 12 weeks with a minimum of 48 hours of rest between training sessions. Dynamic and isometric strength were measured pretraining and posttraining via 1RM and isometric squat, respectively. Data were pooled from pretraining and posttraining testing sessions to examine the relationship between isoinertial and isometric testing variables.

Subjects

Subjects recruited for the study were 17 college-aged males with at least 1 year of resistance training experience using the back squat and a 1RM back squat $>1.3 \cdot$ body mass (BdM) (Table 1). Before participating, all subjects completed a health history questionnaire to screen for any musculoskeletal injuries or health complications that would preclude their participation in the study and signed an informed consent that was approved by the university's Institutional Review Board. Although the subjects in this study were not athletes, their initial strength level was comparable with that in previous research on athletes (1RM: 148.2 ± 23.4 kg, squat to BdM ratio: 1.77 ± 0.2) (12,15).

TABLE 1. Descriptive Statistics.*

	Mean ± *SD*
Age (y)	20.8 ± 1.9
Height (cm)	177.8 ± 6.6
BdM (kg)	83.8 ± 8.5
1RM squat (kg)	148.2 ± 23.4
1RM partial squat (kg)	224 ± 40.1

*BdM = body mass.

Training

After eligibility was determined, the subjects trained 2 $d \cdot wk^{-1}$ for 3 weeks in a strength-endurance phase to equilibrate the training program for all subjects. During this phase, the subjects were familiarized with isometric squats (at 90° and 120° knee angles) to minimize learning effects and to record bar heights for subsequent testing. The subjects were required to complete >80% of the programed volume load to be included in the data analysis.

Training sessions began with a dynamic warm-up using only body weight, followed by warm-up sets on the squat. The subjects followed a block-periodized model with heavy and light days within each microcycle to manage fatigue (33). Load for squat and partial squat was calculated using percentage of pretraining 1RM. All training sessions were supervised by certified strength and conditioning professionals to ensure correct technique and safety. For more specific information about the training completed by the subjects, refer to Bazyler et al. (4).

Testing Procedures

Throughout the study, the subjects were instructed not to participate in any strenuous physical activity 24 hours before testing or training sessions. Dynamic and isometric strength values were measured pretraining and posttraining via 1RM and isometric squat, respectively. Anthropometrics, 1RM squat, and 1RM partial squat at 100° knee angle were measured at the beginning of week 4 and 12 dynamic testing sessions. Isometric squat peak force (IPF), impulse at 250 milliseconds (IMP), and RFD at 250 milliseconds measured at 90° and 120° of knee flexion were assessed during the isometric testing session, which occurred 72–96 hours after dynamic testing.

Dynamic Strength Assessment. Once the subjects arrived, anthropometrics were measured, followed by a dynamic warm-up. The 1RM protocols involved a progressive increase in load and decrease in reps per set. One repetition maximum squat and partial squat attempts were selected with the goal of reaching their maximal effort in 3 attempts after warm-up. Four minutes of rest was given between each attempt. Back squat depth was determined as the top of the leg at the hip joint being below the knee (21). The subjects rested at least 5 minutes between 1RM squat and partial squat testing. For partial squats, the bar was set on safety pins at a height corresponding to 100° of knee flexion, as determined during the familiarization sessions. The subjects performed the concentric portion of the squat to a full lockout position and then lowered the bar back down to the safety pins. The same investigator recorded knee angle and bar height for all testing and training sessions.

Isometric Strength Assessment. Kinetic variables were measured on 0.45-m × 0.91-m dual force platforms affixed side by side (Rice Lake Weighing Systems, Rice Lake, WI, USA) inside a custom designed power rack that allows fixation of the bar at any height, as described previously (5). Analog data from the force plate were amplified and conditioned using a Transducer Techniques amplifier and conditioning module (Temecula, CA, USA). An analog to digital converter collected at 1,000 Hz, and the digitized signal was smoothed using an 11-point moving average (all data points equally weighted) and analyzed using Labview software (version 2010, National Instruments, Austin, TX, USA). Rate of force development was calculated from the force–time curve as the slope of the linear function from 0 to 250 milliseconds. The IMP was calculated from the force–time curve as the integral from 0 to 250 milliseconds. The IPF was determined as the maximal force recorded from each trial. The mean of both trials for each isometric variable was calculated and used for analysis. The same assistant analyzed all force–time curve data.

The subjects performed a dynamic warm-up followed by 2 warm-up attempts at 50 and 75% of perceived maximal effort at 90° angle of the knee. After the 2-minute rest period, 2 maximal efforts were performed with 3 minutes of rest in between trials. The bar was placed across the back in the same position used in training and placed against 2 metal stops to prevent upward movement. The same assistant recorded knee angle and bar height for all testing sessions. The subjects were instructed to maintain "constant tension against the bar" before beginning the test. This was confirmed by the testing assistant via visual feedback of the force–time trace using Labview software. The tester instructed the subjects to "push as fast and as hard as possible." The tester shouted "push," and the participants pushed maximally into the ground until peak force was reached when the tester shouted "stop" to end the test. After completing testing at 90°, the subjects were given 5 minutes of rest, and the same protocol was repeated at a 120° knee angle.

Statistical Analyses

A Shapiro-Wilks normality test was used to determine whether the data were normally distributed. Intraclass correlation coefficients (ICCs) were calculated to determine test-retest reliability. Relative technical error of measurement (TEM) was calculated in a custom Excel (Microsoft Corporation, Redmond, WA, USA) spreadsheet using the formula (9):

$$\text{Relative TEM } (\%) = \frac{100 \times \sqrt{\frac{\sum d_i^2}{2n}}}{\text{Sample Mean Score}}$$

where $\sum d_i^2$ is the sum of the squared differences between test and retest, and n is the sample size. Pearson's product-moment zero-order correlations were used to assess the relationships between dependent variables of the 4 testing methods. To assess the relative strength of the correlations, calculated r-values were evaluated using the following scale: 0.0–0.1 trivial, 0.1–0.3 weak, 0.3–0.5 moderate, 0.5–0.7 strong, 0.7–0.9 very strong, and 0.9–1 nearly perfect (5). For all tests, criteria for statistical significance were set at $p \leq 0.05$. SPSS software (version 20; IBM Co., New York, NY, USA) was used to perform all statistical analyses.

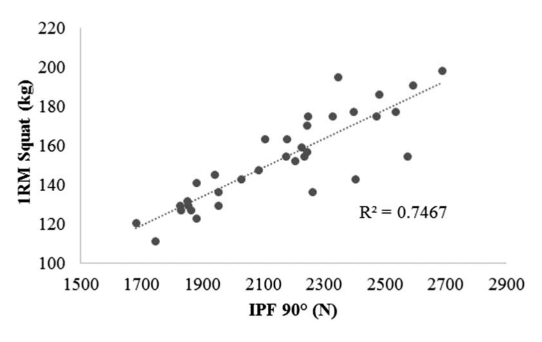

Figure 1. Relationship between 1RM squat and IPF 90°. RM = repetition maximum; IPF = isometric peak force.

RESULTS

The Shapiro-Wilks test indicated that the data were normally distributed for each variable measured ($p > 0.05$). Observed statistical power for the analyses ranged from 0.15 to 0.86. Test-retest reliability for IPF was very good with ICCs of 0.97 and 0.99, and relative TEM of 2.29 and 2.79% for 90° and 120°, respectively. Test-retest reliability for IMP was very good, with ICCs of 0.95 for 90° and 0.97 for 120°, and relative TEM of 4.28% for 90° and 4.34% for 120°. Test-retest reliability for RFD was also very good, with ICCs of 0.90 for both 90° and 120°, although it had a somewhat high relative TEM of 8.12% for 90° and 9.44% for 120°.

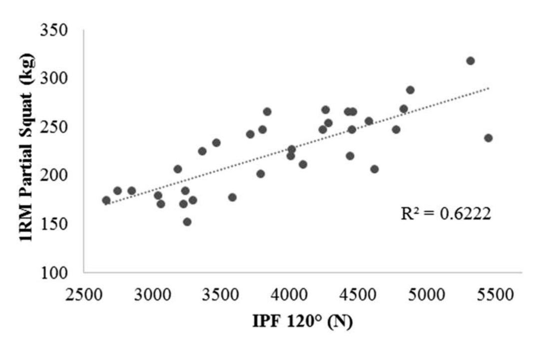

Figure 2. Relationship between 1RM partial squat and IPF 120°. RM = repetition maximum; IPF = isometric peak force.

Table 2. Relationships between isometric and dynamic variables.*

	1RM squat	1RM partial squat	IPF 90°	IPF 120°	IMP 90°	IMP 120°	RFD 90°
1RM partial squat (kg)	0.738†						
IPF 90° (N)	0.864†	0.705†					
IPF 120° (N)	0.597†	0.789†	0.584‡				
IMP 90° ($N \cdot s^{-1}$)	0.697‡	0.726†	0.671†	0.45‡			
IMP 120° ($N \cdot s^{-1}$)	0.575‡	0.616†	0.571‡	0.627†	0.595†		
RFD 90° ($N \cdot s^{-1}$)	0.554†	0.32	0.683†	0.386‡	0.419‡	0.24	
RFD 120° ($N \cdot s^{-1}$)	0.427‡	0.423‡	0.447‡	0.644†	0.294	0.66†	0.443‡

*RM = repetition maximum; IPF = isometric peak force; IMP = impulse; RFD = rate of force development.
†$p < 0.001$.
‡$p < 0.05$.

The 1RM squat and partial squat data were pooled from pretraining and posttraining testing. Pearson product-moment zero-order correlations indicated that there were strong relationships between IPF 90° and 1RM squat, and IPF 120° and 1RM partial squat. These results show that IPF 90° and IPF 120° can account for 75 and 62% of the variance in the 1RM squat and partial squat scores, respectively (Figures 1 and 2). The IMP at 90° and 120° exhibited moderate to strong correlations with the 1RM squat and partial squat, respectively. Isometric RFD at 90° and 120° and 1RM squat and partial squat were weak to moderately associated. All correlations and their statistical outcome can be found in Table 2.

DISCUSSION

The isometric squat performed at 90° and 120° of knee flexion is a reliable measure of peak force in subjects with previous strength training experience. Each seems to be a good predictor of performance on the 1RM squat and partial squat. As noted previously (17,21), IMP and RFD, though reliable, are not as strongly associated with the dynamic maximal strength measures, with RFD exhibiting a higher systematic error. These findings support the use of the isometric squat as a performance measure to monitor changes in strength and explosiveness in the lower extremities during a training program.

Variables obtained from the 90° isometric squat seem to better represent performance in the full squat than variables from the 120° isometric squat, based on the generally higher *r*-values between 90° isometric squat and full squat 1RM. The opposite does not seem to be as consistently true–correlations between PF for the isometric squat at 120° and partial squat 1RM are not substantially higher than those between PF for the isometric squat at 90° and partial squat 1RM. This may be an indication of the importance of learning about isometric force production at the sticking region of a dynamic test of maximal strength, not just the body position in which force production is the highest. This requires further examination however.

Another interesting finding of this study is the somewhat low shared variance between impulse at 90° and 120°, and between RFD at 90° and 120°. Although there is some degree of generality between rapid force production ability, it seems that there is a high amount of joint angle specificity for rapid force production. The ability to produce a high amount of force quickly at 90° does not guarantee the same at 120°. A study by Marcora and Miller (19) found that peak RFD (10-millisecond sliding window) generated in an isometric leg press task at a 120° knee angle was strongly related to squat jump height ($r = 0.71$) and countermovement jump height ($r = 0.69$), whereas peak RFD measured during the same isometric task at a knee angle of 90° was only weakly related to squat jump height ($r = 0.27$) and countermovement jump height ($r = 0.37$). Joint angle specificity to dynamic tasks is supported in other studies as well (26,30).

The isometric squat can be replicated for multiple (2–3) consecutive maximal attempts without negatively affecting testing results; this is evidenced by the strong intrasession reliability found in our study and reported in previous studies for peak force (3,4,23,28,37). An additional finding not reported in previous studies is the apparent low systematic error in peak force measurements. Future research on multi-joint isometric tests should consider including relative TEM or 95% limits of agreement as measures of reliability to complement ICCs. This is particularly important for training interventions to determine whether or not a systematic change has indeed occurred (9). With traditional 1RM testing, there may be discrepancies in 1RM results because of difficulty in selecting appropriate maximal attempts, differences in warm-up protocols, and inability to perform numerous maximal attempts without negatively affecting performance (31). The isometric squat does not seem to be affected by this same limitation, and an accurate measure of maximal strength is not negatively affected by poor choices of previous attempts within a session.

Both IMP and RFD were very reliable, although there was some systematic error in the RFD measure. Rate of force development, as used in this study, has been shown to be reliable in a number of other studies using the isometric midthigh pull and isometric squat (10,21,28,39). Impulse has not been used as extensively as RFD, although it appears to be reliable, with possibly less systematic bias. These findings are supported by Comfort et al. (7) who reported that impulses at 100, 200, and 300 milliseconds were more reliable with a lower smallest detectable difference than maximum RFD during the isometric midthigh pull. For all variables measured from the isometric squat, it is prudent to evaluate the mean of repeated trials (14), and this is especially the case for RFD.

The isometric squat can be used as an informative monitoring tool. An isometric squat performed on force platforms can provide athletes, coaches, and practitioners with changes in force–time curve characteristics at specific body positions. For example, powerlifters may be interested in knowing how strength changes at the sticking region (IPF 90°) as a result of their training program, whereas sprinters may be interested in knowing how impulse changes during specific time intervals (e.g., impulse from 0 to 90 milliseconds). This provides the athlete with more information than simply a 1RM load.

Various knee joint angles have been used during isometric squat testing; however, the most commonly chosen knee joint angles are 90° and 120° (6,20,27,38). Studies that chose to use different knee angles have done so to replicate positions used in training or competition (29,37,39). For researchers, the isometric squat can provide joint angle–specific changes, which are important for training studies interested in task-specific adaptations to training (i.e., at what body positions and joint angles in the squat do changes in strength occur?). To date, only 1 study has reported hip angle during the isometric squat (27). Future studies should consider including hip angle measurements along with knee angle to improve internal validity.

In this study, testing time per subject from warm-up to finish for isometric squats was shorter than that for 1RM squat testing. This is particularly important in athletic settings where National Collegiate Athletic Association regulations limit the number of contact hours an athlete has with the coaching staff. It is also relevant in research settings where time efficiency limits the number of tests that can be included in the testing battery. For this study, the average time it took for a subject to complete 1 isometric squat test was 10 minutes, not including the 5-minute dynamic warm-up before testing. As long as the subjects are spaced in time appropriately (~15 minutes apart), the isometric squat can be performed fairly quickly with an athletic team (or 15–20 subjects). If necessary, for larger teams and subject populations, the testing session can be divided into 2 separate days.

Some practitioners have voiced concern about the safety of the isometric squat because of the rapid compression of cervical vertebrae upon initiation of the test (11,37). Indeed, Wilson et al. (37) eliminated the isometric squat from the testing battery during posttesting because of a subject being injured while performing the test during the midtraining testing. To reduce the risk of injury, the subjects were instructed to position their back on the bar the same way they did during training before initiation of the test. The subjects were instructed to hold this position with constant tension on the bar to ensure that the subjects maintained a rigid torso before the maximal push against the bar. Instant visual feedback of the force–time curve was provided on a computer screen to accomplish this. To terminate the isometric squat test, the subjects stopped pushing against the bar, whereas during a 1RM failed attempt, the spotters had to grab the bar to assist the subject with putting the bar on the rack or lowering it to the safety pins. No subjects reported an injury during the isometric squat testing protocol. A significant consideration when performing any test is whether or not the subjects are familiar with how to perform it. In this study, the subjects performed 2 familiarization sessions per week for 3 weeks before the first testing session. This seemed to have provided ample practice on the test to produce reliable intrasession results. This however can be a limitation to the isometric squat test because it requires more time. A way to improve the benefit–cost ratio would be to include the familiarization sessions at the end of training sessions during introductory mesocycle before the preintervention testing session.

The equipment required to collect (force platform or strain gauge, power rack, AD converter, amplifier) and analyze (software) isometric squat data has limited its accessibility and therefore its popularity in comparison with dynamic tests of maximal strength (23). In addition, sports scientists interested in working with athletes may not have access to this equipment, which further limits the use of the isometric squat as a laboratory-based monitoring tool. However, a number of institutions have reported using multijoint isometric measures to monitor athletes over a training season (5,21,35,38,40).

The isometric squat can only be used to assess changes at specific joint angles and body positions, which may not directly dictate ability to perform a multijoint athletic task (1,25,28,36). Practitioners and researchers considering this idea have suggested avoiding isometric testing for athletes (36). However, previous studies have reported statistically moderate to strong relationships between multijoint isometric tests and dynamic movements such as vertical jumps (17); isometric and dynamic midthigh pulls (10); sprint cycling times (34); 10-m sprint times (35); 1RM squat, power clean, and power snatch (21,22,32); shot put and weighted throw performance (32). Additionally, there are other potential uses for isometric tests, including the isometric squat. As stated previously, the isometric squat can be used to complement isoinertial testing results by providing kinetic data giving a more comprehensive description of changes in strength and explosiveness over a training program. For example, a shot putter may decrease squat displacement in training by performing ½ squats and ¼ squats in consecutive microcycles during a taper leading up to a competition. Performing isometric squats at 120° before and after the taper would provide kinetic data to corroborate the changes in throwing performance. Isometric squats can also be used to assess bilateral strength asymmetries in the lower extremities, which may have application for detecting injury potential (3,16).

Practical Applications

An isometric squat performed at various joint angles is a reliable testing measure that can provide a strong indication of changes in strength and explosiveness as a result of training. The data indicate that peak force is strongly related to 1RM squat and partial squat at the respective joint angles, whereas IMP exhibits moderate to strong relationships and RFD exhibits weak to moderate relationships. Although not all studies agree, there is evidence indicating that multijoint isometric tests have moderate to strong correlations to athletic tasks. This may be important for strength and conditioning professionals and researchers interested in monitoring changes in strength and explosiveness.

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