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Abstract

Isometric multi-joint tests are considered reliable and have strong relationships with 1RM performance. However, limited evidence is available for the isometric squat in terms of effects of familiarization and reliability. This study aimed to assess, the effect of familiarization, stability reliability, determine the smallest detectible difference, and the correlation of the isometric squat test with 1RM squat performance. Thirty-six strength-trained participants volunteered to take part in this study. Following three familiarization sessions, test–retest reliability was evaluated with a 48-hour window between each time point. Isometric squat peak, net and relative force were assessed. Results showed three familiarizations were required, isometric squat had a high level of stability reliability and smallest detectible difference of 11% for peak and relative force. Isometric strength at a knee angle of ninety degrees had a strong significant relationship with 1RM squat performance. In conclusion, the isometric squat is a valid test to assess multi-joint strength and can discriminate between strong and weak 1RM squat performance. Changes greater than 11% in peak and relative isometric squat performance should be considered as meaningful in participants who are familiar with the test.

Keywords: strength-trained, responsiveness, stability reliability, squat performance

Introduction

Strength tests are used to determine an athlete's responsiveness to a training program or current level of performance (Kraska et al., 2009). This information can be utilized to prescribe optimal loading in athlete's training programs (Suchomel, Nimphius, & Stone, 2016). When determining maximum strength in athletes, the one repetition maximum test (1RM) has traditionally been used (Appleby, Newton, & Cormie, 2012; Buckner et al., 2016; Loturco et al., 2016). Whilst the 1RM squat is considered reliable (Comfort & McMahon, 2015) the implementation of 1RM tests can be challenging due to variability in methodological approaches to control range of motion (McMaster, Gill, Cronin, & McGuigan, 2014), the requirement for squatting skill under a maximal external load (Ploutz-Snyder & Giamis, 2001) and the lack of practicality with novice, elderly or functionally limited participants (Jidovtseff, Harris, Crielaard, & Cronin, 2011). Regular 1RM testing can also take significant time away from training (Banyard, Nosaka, & Haff, 2017) with congested competition schedules and large groups of players in team sports being further limitations to implementing 1RM tests (Loturco et al., 2016) within applied settings.

As an alternative to 1RM testing, isometric multi-joint tests (IMJT) are used to test maximum strength and are considered easier to standardize than 1RM tests (Bazyler, Beckham, & Sato, 2015). Given IMJTs are easily controlled and have minimal skill requirement (Wang et al., 2016), theoretically they could improve the reliability and responsiveness of strength measurements and have greater practical impact for coaches to interpret change over time. IMJTs are very strongly related to 1RM strength performance (McGuigan, Newton, Winchester, & Nelson, 2010; Suchomel et al., 2016) and have been shown to discriminate between strong and weak athlete groups (Bailey, Sato, Burnett, & Stone, 2015a; Kraska et al., 2009; Thomas, Jones, Rothwell, Chiang, & Comfort, 2015). IMJTs have also been utilized to assess acute fatigue response to maximum strength training (Kennedy & Drake, 2017; Storey, Wong, Smith, & Marshall, 2012) and are deemed appropriate to evaluate responsiveness over time (Drake, Kennedy, & Wallace, 2017).

Understanding reliability of strength testing is a key pillar to interpret the responsiveness of athletes to training programs (Hopkins, 2004). The responsiveness of a test is a crucial component of validity defined as, the ability of a test to detect change over a time (Terwee et al., 2007). Responsiveness is best described with respect to the smallest detectible difference (SDD) calculated based on a test-retest study design (Beckerman et al., 2001). To determine the SDD, the length of time between test-retest should be ecologically appropriate to assess the stability of the variables of interest between tests (Comfort & McMahon, 2015; Davidson & Keating, 2014). This between day test–retest reliability is defined by Baumgarter (1989) as stability reliability. Stability reliability assessments are preferential over between trial designs as they account for systematic bias affecting performance tests (Atkinson & Nevill, 1998; Ritti-Dias, Avelar, Salvador, & Cyrino, 2011; Taylor, Cronin, Gill, Chapman, & Sheppard, 2010). The implementation of stability reliability designs in IMJT investigations are currently limited (Drake et al., 2017) therefore further work is required to understand reliability and responsiveness.

Acknowledging the stability reliability investigations using the isometric mid-thigh pull (Comfort, Jones, McMahon, & Newton, 2015; Dos'Santos, Thomas, & Oakley, 2017), we are aware of only one study using the isometric squat test (Palmer, Pineda, & Durham, 2017) that enables the calculation of SDD. The study by Palmer et al.

(2017) was conducted in female only participants thus limiting generalizability. Despite the known effects of familiarization on isometric testing (Calder & Gabriel, 2007; Dos'Santos et al., 2017; Maffiuletti et al., 2016) authors in the field continue to not provide the measured effects of familiarization in IMJTs. Studies should evaluate the familiarization effects rather simply stating that one session was completed (Brady, Harrison, Flanagan, Haff, & Comyns, 2017; Comfort et al., 2015; Palmer et al., 2017) or that participants were familiarized (Dos'Santos et al., 2017) by providing measured familiarization data.

Following a measured familiarization period, the purpose of this study was to (1) assess the stability reliability of the isometric squat test in absolute and relative terms, (2) determine the SDD to enable assessment of responsiveness, (3) assess the strength of the relationship between the isometric squat test and the commonly assessed 1RM back squat and (4) use the isometric squat to discriminate between strong vs weak 1RM back squat performers. It was hypothesized that the isometric squat would demonstrate a high level of relative reliability (ICC ≥ .70), low level of absolute error, and strong-significant relationship with the dynamic criterion test (r > .70). Additionally, isometric squat performance would effectively discriminate between strong vs weak 1RM squat performers.

Methods

Experimental Design

A within-subject repeated measures design was implemented to assess familiarization and reliability of the isometric squat test. Three familiarization sessions were conducted followed by test and retest reliability sessions, with 48 hours between each test. Familiarization sessions followed the procedures of the test and retest sessions (provided in procedures section). A 1RM Squat test was completed post isometric squat in the retest session. All testing sessions were standardized to the nearest hour of the day from familiarization session one to account for circadian rhythmicity (Teo, McGuigan, & Newton, 2011). Participants were asked to maintain their normal physical activity level and nutritional habits but refrain from strength training or taking any ergogenic aid throughout involvement in this study.

Participants

A power analysis program (G*Power, 3.1) was used to generate the optimal sample size a priori using the guidance procedure by Faul, Erdfelder, Buchner, and Lang (2009). Type I error for two tailed test and power were inputted as per conventional levels (5% for type I error and 80% for power) as described by Charles, Giraudeau, Dechartres, Baron, and Ravaud (2009). The priori power analysis revealed a required participant group of 42 and critical t value of 2.02. Forty-two strength trained males volunteered for participation (age: 21.4±4.5 years, height: 1.86±0.06 m, mass: 93.5±12.4 kg, strength training experience: 4.1±1.8 years). Eligibility for participation required greater than six months' experience in strength training and previously experience in 1RM strength testing using the squat exercise. Ethical approval was provided by the University institutional review board (Ulster University), and all athletes provided written informed consent. All procedures within this investigation conformed to the Declaration of Helsinki. All 42 participants remained within the study group until familiarisation session 3, at which point 39 completed. Thirty-eight participants completed the first testing session with 36 completing the retest and the 1RM testing. Six participants were unable to attend testing at the specific times to maintain circadian rhythmicity and were withdrawn from further involvement. In total, the completion rate of the study was 85.7% with 36 completed participants' data used for further analysis.

Procedures

Warm up

A standardized warm-up comprising five minutes of easy jogging followed by dynamic preparatory movements such as squatting and lunging was undertaken by all participants before isometric and 1RM squat testing. In preparation for isometric squat tests, participants completed warm-up repetitions at self-determined estimated 75% and 90% of maximal effort prior to maximal testing. Prior to maximal 1RM squat efforts to ninety degrees of knee flexion angle, participants completed 3 repetitions at 50%, 2 at 80%, and 1 at 90% of self-estimated 1RM.

Isometric squat

Isometric squat was assessed at a knee angle of 90° (IS^{90}) using a custom isometric rack (Samson Equipment Inc, NM, USA) with adjustable settings to the nearest 2.5 cm of vertical displacement. The knee angle was chosen as this approximately reflects the sticking point during the squat exercise (Bazyler, Sato, Wassinger, Lamont, & Stone, 2014). All participants performed the test at the same relative knee angle, measured using a handheld goniometer (66fit Ltd Lincolnshire, UK) by the lead investigator. The isometric rack was positioned directly over two force plates (Kistler type 9286BA, Winterthur, Switzerland) connected to an A/D converter (Kistler type 5691A1, Winterthur, Switzerland). The desired position for testing required participants to stand on the force plate with their feet approximately shoulder width apart, trunk near-vertical, and the immoveable horizontal bar placed above the posterior deltoids at the base of the neck. This position was established before each trial, with the joint angle confirmed using goniometry. Participants' stance widths were monitored using a standard measuring tape to ensure consistency between trials. Participants were advised to maintain a constant and minimal pre-tension until the tester gave verbal instruction, "2, 1, GO" upon which participants were cued to "push against the ground as hard and as fast as possible". This external focus of attention has previously been reported to optimize peak force output (Halperin, Williams, Martin, & Chapman, 2016). All participants were given verbal encouragement during each trial. Temporal and vertical ground reaction force (F_z) data were collected at a sampling frequency of 1000 Hz for a five second sampling period using Bioware® software (Version 5.1, Type 2812A). Trials were terminated when a plateau in the force time trace was visually observed (Bazyler et al., 2014). The force plate was zeroed immediately before each trial and sampling began on the verbal command. Each participant completed two maximal effort trials with three minutes of passive rest in between with the average of both trials used for further analysis.

1RM squat

The 1RM squat to a knee flexion angle of 90° was performed according to the exercise technique outlined by Chandler (1991) using a standard 20 kg Olympic barbell and plates (Eleiko AB, Halmstad, Sweden) for loading. Participants were instructed to adopt a shoulder width stance in keeping with their normal squat stance, descend in a controlled manner, avoid bouncing at the bottom positon, maintain as near a vertical torso as possible and feet always flat on the ground. Each 1RM trial was performed to an adjustable metal box placed directly at the heels of the participant marked with athletic tape to ensure consistency in the horizontal displacement from the box and enabled kinesthetic feedback to standardize the vertical displacement. Participants were not permitted to pause or sit on the box. Each trial was visually monitored by the lead investigator to ensure appropriate technique was maintained and the required eccentric phase displacement was satisfied. Verbal encouragement was provided throughout maximal testing. Following the last warm-up effort, participants were instructed to progressively increase bar load in 1.25 to 5kg increments per trial based on their perception of effort until a maximum load was lifted. Participants were permitted to repeat any failed lifts on one occasion only. For all squat trials a linear position transducer (GymAware. Kinetic Performance Technologies, Canberra, Australia) was attached to one side of the barbell to measure bar velocity and displacement which was subsequently analyzed using custom software (GymAware Version 3.13, Kinetic Performance Technologies). Mean concentric velocity was assessed and used for feedback to participants after each trial to adjust bar loading based on the critical velocity to successfully complete a 1RM trial (Loturco et al., 2016). This variable has a coefficient of variation (CV) of 0.57% when assessing the 1RM squat (Sanchez-Medina & Gonzalez-Badillo, 2011).

Statistical analysis

Prior to analysis data were visually inspected for normality. Box plots of all dependent variables were inspected with no data outliers detected in test-retest time points. A Shapiro-Wilks normality test assessed the distribution of the data with Levene's test checking the homogeneity of variance. Stability reliability was assessed using a Bland Altman analysis (Bland & Altman, 1986) to determine the level of agreement between test-retest measures and examine proportional bias. Intraclass correlation coefficients

(ICC; 3,1) and their 95% confidence intervals (CI), standard error of measurement (SEM), and coefficient of variation (CV) were calculated on test-retest data. ICC was interpreted using the criteria of Cortina (1993), whereby ICC ≥0.80 is highly reliable. SDD was calculated to enable interpretation of performance change over time for this test. The equations used within this study were; $\boldsymbol{SEM} = SD \times \sqrt{1 - ICC}$, $\boldsymbol{SDD} = 1.96 \times \sqrt{2} \times SEM$ (Beckerman et al., 2001; Weir, 2005). A general linear model repeated measures ANOVA was used to examine the impact of familiarization on kinetic performance variables across the five testing sessions. Mauchly's test of sphericity was applied and if violated, the Greenhouse-Geisser correction factor was used. Where appropriate, post-hoc analyses of significant effects were performed using the Huynh-Feldt correction method. Independent *t* tests were used to assess the difference between strong and weak groups, determined by percentile division of the total sampled participants. Strong participants were identified as the top 25% with weaker participants defined within the bottom 25% (Bailey et al., 2015a; Bailey, Sato, Burnett, & Stone, 2015b). This approach was repeated for IS^{90} peak, net and relative force variables independently as participants may have a high level of absolute strength but not necessarily a high level of relative strength due to effects of body mass (Folland, Mc Cauley, & Williams, 2008). Effect size (ES) was calculated by dividing the between group difference by the pooled standard deviation to determine the magnitude of difference between groups and classified as trivial (< 0.2), small (0.2 – 0.6), moderate (0.6 – 1.2), large (1.2 – 2.0), and very large (2.0 – 4.0) (Hopkins, Marshall, Batterham, & Hanin, 2009). Statistical significance was set at $P \leq 0.05$. Pearson's correlation assessed the relationship between IS^{90} kinetic variables and 1RM squat performance using the previous discussed thresholds (Hopkins, 2002). All statistical calculations were performed using IBM SPSS Statistics 22 software (SPSS

Inc., Chicago, IL, USA).

Results

Shapiro-Wilk's test revealed all IS^{90} & 1RM variables were normally distributed. Repeated measures ANOVA showed that Mauchly's test of sphericity was violated (χ^2 (9) = 19.13, p = .24; χ^2 (9) = 19.34, p = .23; χ^2 (9) = 17.27, p = .45) for IS^{90} peak, net and relative force variables respectively. Degrees of freedom were adjusted using the Huynh-Feldt correction. A significant main effect was found across testing time points, F (3.68, 128.7) = 9.23, p < .001. Bonferroni post hoc comparisons revealed significant increases in peak force, net force and relative force between familiarization 1 to 3, and between familiarization 2 to 3 ($p \leq$ .002). Non-significant differences were found between familiarization 3 to test session, and between test to retest sessions. Statistics provided in table 1 and figure 1.

******TABLE 1 ABOUT HERE******

******FIGURE 1 NEAR HERE******

Test-retest IS^{90} force variables were highly reliable (ICC = .856 - .910, 95% CI [.735 to .953], CV = 3.78 - 6.11%). Standard error of measurement was 98.62N, 97.53N, and 1.04N·kg^{-1} for peak, net and relative IS^{90} force variables respectively. Reliability statistics provided in table 2.

******TABLE 2 ABOUT HERE******

Bland Altman analysis showed in test-retest conditions, IS^{90} peak force had a bias of -14.98N (precision -32.12 to 62.09; limits of agreement -257.93 to 287.9), IS^{90} net force had a bias of -14.08N (precision -32.64 to 60.81; limits of agreement -256.58 to

284.75) and IS^{90} relative force had a bias of -.161N·kg^{-1} (precision -.34 to .66; limits of agreement -2.72 to 3.05). No proportional bias was detected for any of the IS^{90} variables (p = .757, .940 and .637 for peak, net and relative force respectively).

******FIGURE 2, 3 & 4 NEAR HERE******

IS^{90} peak force demonstrated a significant large correlation with 1RM load. IS^{90} net force demonstrated a significant large correlation with 1RM load, and significant moderate correlation with 1RM relative load. IS^{90} relative force demonstrated a significant large correlation with 1RM relative load. Correlation coefficients are provided in table 2.

Levene's test for equality of variances was non-significant (p = .083 - .723), therefore group variances were treated as equal for subsequent independent t tests. Based on IS^{90} peak force (Strong ≥ 2689N; Weak ≤ 2276N), very large significant differences were found between strong and weak groups for 1RM load (p = .000, ES = 2.4) but small non- significant between group differences in 1RM relative load (p = .619, ES = .2). Based on IS^{90} net force (Strong ≥ 1771N; Weak ≤ 1365N), very large significant differences were present between strong and weak groups for 1RM load (p = .000, ES = 2.1) and large significant difference in 1RM relative load (p = 0.023, ES = 1.2). Group splits based on IS^{90} relative force (Strong ≥ 29.6N·kg^{-1}; Weak ≤ 24.1N·kg^{-1}), moderate significant differences were present between strong and weak groups for 1RM load (p = .03, ES = 1.1) and very large significant difference in 1RM relative load (p = 0.000, ES = 2.7). 1RM mean concentric velocity for all participants was 0.294 ± 0.086 m/s. Trivial to small non-significant differences were found between strong and weak groups in mean concentric velocity. Group comparisons presented in table 3.

****TABLE 3 ABOUT HERE****

Discussion

This study aimed to assess the stability reliability of the IS^{90} test having accounted for familiarization. Calder and Gabriel (2007) suggest that intentional or unintentional effects of familiarization are important to consider when interpreting studies assessing reliability and responsiveness. Changes in force output during familiarization can be influenced by multiple factors beyond true changes in muscle strength, such as learning execution technique, tolerance of maximal loads, increased motor unit recruitment (Amarante do Nascimento et al., 2013) and decreases in antagonist co-contraction (Calder & Gabriel, 2007). Notably, this study found participants with an average strength training experience of 4.1 years required three familiarization sessions prior to stabilization of effects. Prior investigations using isometric multi-joint tests report a familiarization was undertaken before testing but neglect to demonstrate the stabilization of learning effects prior to the assessment of reliability (Bazyler et al., 2014; Haff, Ruben, Lider, Twine, & Cormie, 2015). As such, observed learning effects within this study are not comparable to previous studies although they may be generalizable to similar strength trained populations. However, familiarization effects during a 1RM squat test were found to stabilize after approximately three sessions (Soares-Caldeira et al., 2009), corroborating with the findings in this study.

Very high to nearly perfect relative reliability was found for IS^{90} variables between test and retest sessions. No systematic bias was found between test-retest sessions with Bland-Altman analysis revealing no proportional bias exists between measures. Stability reliability measures within this study are congruent with resistance strength trained female participants (Palmer et al., 2017) assessed in isometric half squatting

(ICC 0.84; CV 11.2%). Furthermore, our findings agree with two previous studies assessing isometric mid-thigh pulls which demonstrated very high to nearly perfect stability reliability (ICC 0.86; CV < 7%) in seventeen adolescent athletes (Thomas, Dos'Santos, Comfort, & Jones, 2017) and nearly perfect (ICC 0.96; CV < 4.3%) in fourteen male athletes (Thomas, Comfort, Chiang, & Jones, 2015). Additionally, high reliability found for IS^{90} variables in this study are comparable to the reliability (ICC > .969) reported for 1RM squat test (Comfort & McMahon, 2015) and as stated in the review by Pereira and Gomes (2003), ICC values ranging between .79 and .99 were found dependent on gender and type of test. Overall, the findings of this study suggest a high level of relative reliability and low level of absolute error associated with the stability reliability of isometric squat testing. This provides evidence for the use of the IS^{90} as a reliable monitoring tool, which is a key requirement to monitor training effects over time (Atkinson & Nevill, 1998).

The SDD was determined as 274 N, 270 N, and 2.9 $N \cdot kg^{-1}$ for IS^{90} peak force, net force and relative force respectively, corresponding to changes of 11% in peak, 17% in net and 11% in relative force required to demonstrate meaningful change beyond the error of the test. Reported SDD for IMTP peak force in Dos'Santos et al. (2017) was 9% which is comparable to our findings. However, both our findings and Dos'Santos et al. (2017) demonstrate lower SDD than recently reported by Palmer et al. (2017) of ~30% for the isometric half squat or Thomas et al. (2017) of 28% in the IMTP. The heterogeneity of participants in the above studies may explain the observed variance between reported SDD. Our results reflect a larger cohort of strength trained adult participants (males) than previously reported. The SDD of isometric force is central in enabling the assessment of responsiveness of training interventions in future studies with comparable populations.

Results showed 1RM load has a significant correlation with IS^{90} peak force (r = .688) and IS^{90} net force (r = .616). 1RM relative load has a significant correlation with IS^{90} relative force (r = .759) and significant correlation IS^{90} net force (r = .419). The strength of these relationships corroborates with previous reported correlations between isometric squats with 1RM squat. Nuzzo, McBride, Cormie, and McCaulley (2008) found large significant correlation (r = .624) between $IS^{140\ knee}$ and $1RM^{70\ knee}$, with Blazevich, Gill, and Newton (2002) showing similar very large significant correlation (r = .77) between $IS^{90\ knee}$ and $1RM^{110\ knee}$. Bazyler et al. (2014) demonstrated the effects of joint angle on the corresponding relationship with the 1RM performance, where $IS^{90\ knee}$ has a very large relationship (r = .864) with 1RM back squat and $IS^{120\ knee}$ has a moderate relationship (r = .597). Such findings illustrate the importance of testing angle selection and explains a proportion of variation amongst correlational statistics between 1RM and IMJTs.

Strength of correlations between 1RM squat and isometric squat will largely be affected by the technical skill and experience of the participants (Abernethy, Wilson, & Logan, 1995), as well as the utilization of the strength shortening cycle to contribute to force expression in the 1RM (Baker, Wilson, & Carlyon, 1994). It is therefore unlikely a perfect correlation will exist between 1RM squat and isometric squat, although we surmise that the concentric contraction force capacity would be nearly perfectly correlated with isometric contraction force. Monitoring of concentric contraction velocity within this study verified 1RM efforts were truly maximal (0.294 ± 0.086 m/s for participants last successful effort) in corroboration with existing evidence (Loturco et al., 2016), allowing future comparisons to be made. The large to very large correlations observed between IS^{90} and 1RM performance observed in this study and consistently in other published work demonstrates appropriate criterion validity for the IS^{90} to be used to evaluate strength performance instead of 1RM testing. We subscribe to the viewpoint that testing angle is important to correspond to the range of motion of the training exercise and the portion of the exercise where the sticking region occurs (Blazevich et al., 2002).

Significantly higher isometric strength corresponds to greater jump performance (Kraska et al., 2009; Secomb et al., 2016) and cycling performance (Stone et al., 2004) compared to weaker participants. Thomas, Jones, et al. (2015) suggested that it is unknown whether significant differences in relative isometric strength measurements would transfer to relative dynamic strength, such as the 1RM back squat. In this study, between group analysis showed IS^{90} net force and relative force capacity successfully discriminated between 1RM and relative 1RM performance. Furthermore, IS^{90} peak force discriminated between 1RM load but not relative 1RM performance. These results confirm that isometric relative strength does transfer as relative dynamic strength in the population studied in this investigation. Overall, our findings support the use of the IS^{90} as a valid tool for assessing strength capacity and present a case that IS^{90} does discriminate between dynamic strength capacity. With very large relationships reported between IMJTs and 1RM performance (McGuigan, Winchester, & Erickson, 2006), Blazevich et al. (2002) reports IMJT measures could be used to predict 1RM performance therefore enabling estimated training loads for dynamic exercises. Research pertaining to predictive approaches may find strongest validity in isometric net and relative variables as these have discriminated most clearly within this study between 1RM performance.

Conclusion

To achieve reliable isometric strength data, pre-testing practice sessions are required to account for the effects of familiarization. Isometric squats require less repetitions or time comparatively to traditional 1RM testing which enhances practicality and implementation into athlete's schedules. Under test retest conditions this study has demonstrated that the IS^{90} is highly reliable. When evaluating strength trained athletes, 11% increases in peak or relative force represent meaningful differences beyond the error of the test. IS^{90} discriminates between strong and weak performers in the 1RM squat and therefore can be used as an alternative method of evaluating strength beyond the conventional 1RM method.

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Figure 1.

Box plot for IS^{90} peak force across testing sessions.

* indicates significant difference from familiarization session 1 ($p < .001$). † indicates significant difference from familiarization session 2 ($p < .05$).

Figure 2.

Bland Altman plot for IS^{90} Peak Force. Solid line represents the mean difference; dashed lines represent 95% limits of agreement.

Figure 3.

Bland Altman plot for IS^{90} Net Force. Solid line represents the mean difference; dashed lines represent 95% limits of agreement.

Figure 4.

Bland Altman plot for IS^{90} Relative Force. Solid line represents the mean difference; dashed lines represent 95% limits of agreement.

TABLE 1. Effects of familiarization on force variables

Test session	Familiarization 1 - 2	Familiarization 2 - 3	Familiarization 3 - Test	Test - Retest
Δ $IS^{90\ Peak}$ force (N)	45.61	91.15*	-38.42	-14.98
SD	145.5	133.1	138.7	139.2
p	0.683	0.002	1.00	1.00
Effect Size	-0.157	-0.315	0.13	0.05
CV	4.17	3.92	3.97	3.81
Δ IS^{90} Net force (N)	45.34	92.19*	-39.94	-14.08
SD	145.9	131.0	138.0	138.1
p	0.706	0.002	0.913	1.00
Effect Size	-0.191	-0.378	0.16	0.054
CV	6.52	6.00	6.30	6.11
Δ IS^{90} Relative force ($N{\cdot}kg^{-1}$)	0.536	1.03*	-0.433	-0.161
SD	1.69	1.48	1.53	1.47
p	0.657	0.002	0.982	1.00
Effect Size	-0.182	-0.319	0.127	0.046
CV	4.23	3.72	3.97	3.78

*represents a significant difference between testing time points

Abbreviations: N = newton; $N{\cdot}kg^{-1}$ = newton per kilogram of body mass; SD = standard deviation; CV = coefficient of variation

Table 2

TABLE 2. Between test reliability variables and correlations with 1RM performance

Reliability Variable	Test Mean ± SD	Retest Mean ± SD	ICC (95% CI)	SEM (95% CI)	CV	SDD (as %)	Correlation with 1RM Load lifted (kg)	Correlation with 1RM Relative strength (kg/kg)
$IS^{90\ Peak}$ force (N)	2509.72 ± 287.19	2494.74 ± 294.42	.885 (.787, .940)	98.62 (71.1, 126.1)	3.88	273.35 (10.92)	.688**	0.099
IS^{90} Net force (N)	1591.78 ± 256.13	1577.69 ± 257.87	.856 (.735, .924)	97.53 (70.2, 124.9)	6.11	270.33 (17.06)	.616**	.419**
IS^{90} Relative force ($N \cdot kg^{-1}$)	27.1 ± 3.53	26.94 ± 3.41	.910 (.830, .953)	1.04 (-1.8, 3.9)	3.78	2.88 (10.67)	0.244	.759**

*represents a significant correlation between variables, p <.001.

Abbreviations: N = newton; $N \cdot kg^{-1}$ = newton per kilogram of body mass; SD = standard deviation; ICC = intraclass correlation coefficient; SEM = standard error of measurement; CV = coefficient of variation; SDD = smallest detectible difference.

Table 3

TABLE 3. 1RM performance comparison based on IS^{90} determined strong and weak groups

Grouping variable	**IS^{90} Peak force (N)**		**IS^{90} Net force (N)**		**IS^{90} Relative force ($N \cdot kg^{-1}$)**	
	1RM Load (kg)	**Relative 1RM Load (kg/kg)**	**1RM Load (kg)**	**Relative 1RM Load (kg/kg)**	**1RM Load (kg)**	**Relative 1RM Load (kg/kg)**
Strong group (n=9)	195.8 ± 15.41	1.96 ± .256	195.6 ± 15.7	2.08 ± .273	182.8 ± 16.41	2.13 ± .202
Weak group (n=9)	160 ± 14.57	1.90 ± .184	166.7 ± 11.72	1.79 ± .209	167.8 ± 9.39	1.66 ± .146
p	0.000	0.619	0.000	0.023	0.03	0.000
Effect size	2.4	0.2	2.1	1.2	1.1	2.7
Effect size interpretation	Very large	Small	Very large	Large	Moderate	Very large

Abbreviations: N = newton; $N \cdot kg^{-1}$ = newton per kilogram of body mass; Strong and weak group data are presented as means ± SD.

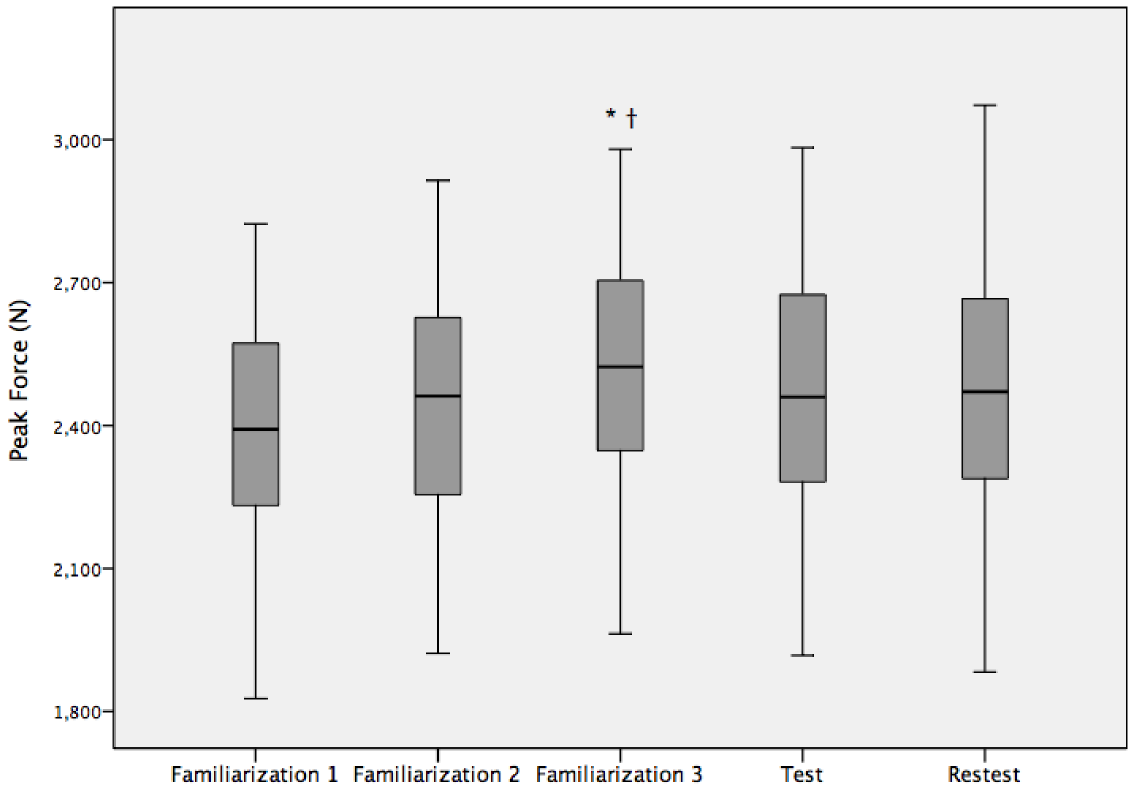

Figure 1.

Box plot for IS^{90} peak force across testing sessions.

* indicates significant difference from familiarization session 1 ($p < .001$). † indicates significant difference from familiarization session 2 ($p < .05$).

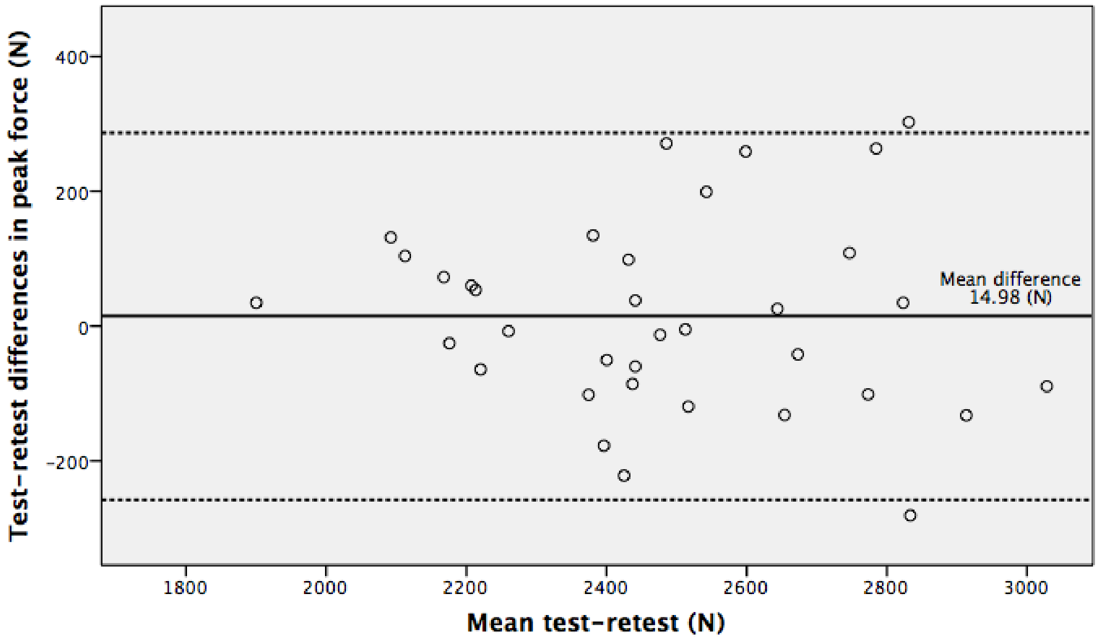

Figure 2.

Bland Altman plot for IS^{90} Peak Force. Solid line represents the mean difference; dashed lines represent 95% limits of agreement.

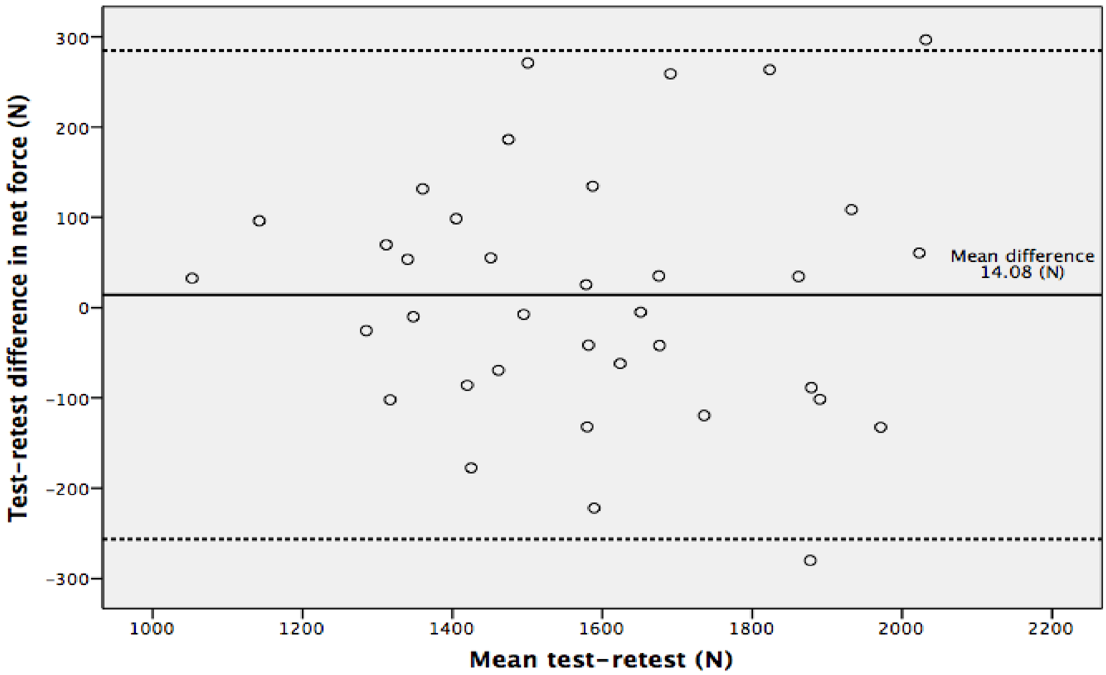

Figure 3.

Bland Altman plot for IS^{90} Net Force. Solid line represents the mean difference; dashed lines represent 95% limits of agreement.

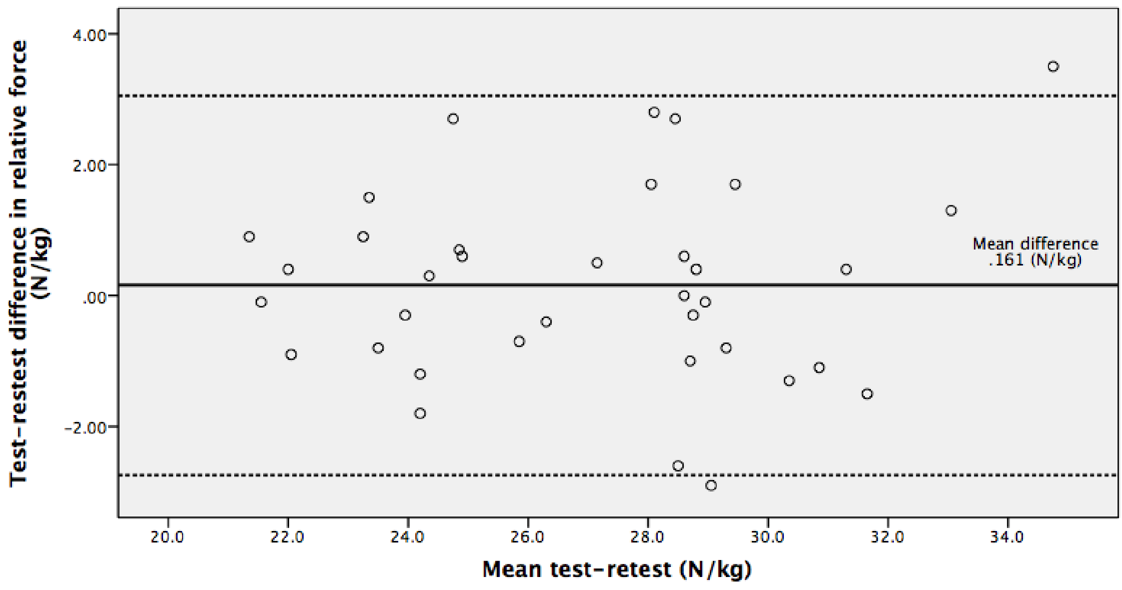

Figure 4.

Bland Altman plot for IS^{90} Relative Force. Solid line represents the mean difference; dashed lines represent 95% limits of agreement.