Familiarization, validity and smallest detectable difference of the isometric squat test in evaluating maximal strength

Drake, D., Kennedy, R., & Wallace, E. S. (2018). Familiarization, validity and smallest detectable difference of the isometric squat test in evaluating maximal strength. *Journal of Sports Sciences*, 36(18), 2087-2095. [18]. <https://doi.org/10.1080/02640414.2018.1436857>

[Link to publication record in Ulster University Research Portal](#)

Published in:
Journal of Sports Sciences

Publication Status:
Published (in print/issue): 01/01/2018

DOI:
[10.1080/02640414.2018.1436857](https://doi.org/10.1080/02640414.2018.1436857)

Document Version
Author Accepted version

General rights
Copyright for the publications made accessible via Ulster University's Research Portal is retained by the author(s) and / or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights.

Take down policy
The Research Portal is Ulster University's institutional repository that provides access to Ulster's research outputs. Every effort has been made to ensure that content in the Research Portal does not infringe any person's rights, or applicable UK laws. If you discover content in the Research Portal that you believe breaches copyright or violates any law, please contact pure-support@ulster.ac.uk.

Manuscript Title: Familiarization, validity and smallest detectable difference of the isometric squat test in evaluating maximal strength

Running Title: Validity of the isometric squat test

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

Word Count: 3988

Authors: David Drake^{1,2*}, Rodney Kennedy^{1,3} and Eric Wallace^{1,3}

Department/Institution: ¹ School of Sport, Ulster University; ² Ulster Rugby, Irish Rugby Football Union; ³ Sport and Exercise Science Research Institute, Ulster University

Corresponding Author Details*: School of Sport, Ulster University, Jordanstown, Shore Road, Newtownabbey, Co. Antrim, BT37 0QB, N. Ireland.

Email: daviddrake87@gmail.com

Phone: +44 7442495722

Twitter: @d_drakey

ORCID: orcid.org/0000-0003-0440-7097

Postal address (all authors): As per corresponding author.

Dr Rodney Kennedy: *email* r.kennedy@ulster.ac.uk; *phone* +44 28 90366242

Prof Eric Wallace: *email* es.wallace@ulster.ac.uk; *phone* +44 28 90366535

Disclosure Statement: No external financial support was received for the completion of this study. The authors have no conflicts of interest.

Abstract

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

30 Isometric multi-joint tests are considered reliable and have strong relationships with
31 1RM performance. However, limited evidence is available for the isometric squat in
32 terms of effects of familiarization and reliability. This study aimed to assess, the effect
33 of familiarization, stability reliability, determine the smallest detectible difference, and
34 the correlation of the isometric squat test with 1RM squat performance. Thirty-six
35 strength-trained participants volunteered to take part in this study. Following three
36 familiarization sessions, test–retest reliability was evaluated with a 48-hour window
37 between each time point. Isometric squat peak, net and relative force were assessed.
38 Results showed three familiarizations were required, isometric squat had a high level
39 of stability reliability and smallest detectible difference of 11% for peak and relative
40 force. Isometric strength at a knee angle of ninety degrees had a strong significant
41 relationship with 1RM squat performance. In conclusion, the isometric squat is a valid
42 test to assess multi-joint strength and can discriminate between strong and weak 1RM
43 squat performance. Changes greater than 11% in peak and relative isometric squat
44 performance should be considered as meaningful in participants who are familiar with
45 the test.

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

54 **Introduction**

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79

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).

84

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 detectable 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 Baumgartner (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.

100

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.

105 (2017) was conducted in female only participants thus limiting generalizability.
106 Despite the known effects of familiarization on isometric testing (Calder & Gabriel,
107 2007; Dos'Santos et al., 2017; Maffiuletti et al., 2016) authors in the field continue to
108 not provide the measured effects of familiarization in IMJTs. Studies should evaluate
109 the familiarization effects rather simply stating that one session was completed (Brady,
110 Harrison, Flanagan, Haff, & Comyns, 2017; Comfort et al., 2015; Palmer et al., 2017)
111 or that participants were familiarized (Dos'Santos et al., 2017) by providing measured
112 familiarization data.

113
114 Following a measured familiarization period, the purpose of this study was to (1)
115 assess the stability reliability of the isometric squat test in absolute and relative terms,
116 (2) determine the SDD to enable assessment of responsiveness, (3) assess the strength
117 of the relationship between the isometric squat test and the commonly assessed 1RM
118 back squat and (4) use the isometric squat to discriminate between strong vs weak
119 1RM back squat performers. It was hypothesized that the isometric squat would
120 demonstrate a high level of relative reliability ($ICC \geq .70$), low level of absolute error,
121 and strong-significant relationship with the dynamic criterion test ($r > .70$).
122 Additionally, isometric squat performance would effectively discriminate between
123 strong vs weak 1RM squat performers.

124

125 **Methods**

126 *Experimental Design*

127 A within-subject repeated measures design was implemented to assess familiarization
128 and reliability of the isometric squat test. Three familiarization sessions were
129 conducted followed by test and retest reliability sessions, with 48 hours between each

130 test. Familiarization sessions followed the procedures of the test and retest sessions
131 (provided in procedures section). A 1RM Squat test was completed post isometric
132 squat in the retest session. All testing sessions were standardized to the nearest hour
133 of the day from familiarization session one to account for circadian rhythmicity (Teo,
134 McGuigan, & Newton, 2011). Participants were asked to maintain their normal
135 physical activity level and nutritional habits but refrain from strength training or taking
136 any ergogenic aid throughout involvement in this study.

138 *Participants*

139 A power analysis program (G*Power, 3.1) was used to generate the optimal sample
140 size a priori using the guidance procedure by Faul, Erdfelder, Buchner, and Lang
141 (2009). Type I error for two tailed test and power were inputted as per conventional
142 levels (5% for type I error and 80% for power) as described by Charles, Giraudeau,
143 Dechartres, Baron, and Ravaud (2009). The priori power analysis revealed a required
144 participant group of 42 and critical t value of 2.02. Forty-two strength trained males
145 volunteered for participation (age: 21.4 ± 4.5 years, height: 1.86 ± 0.06 m, mass:
146 93.5 ± 12.4 kg, strength training experience: 4.1 ± 1.8 years). Eligibility for participation
147 required greater than six months' experience in strength training and previously
148 experience in 1RM strength testing using the squat exercise. Ethical approval was
149 provided by the University institutional review board (Ulster University), and all
150 athletes provided written informed consent. All procedures within this investigation
151 conformed to the Declaration of Helsinki. All 42 participants remained within the
152 study group until familiarisation session 3, at which point 39 completed. Thirty-eight
153 participants completed the first testing session with 36 completing the retest and the
154 1RM testing. Six participants were unable to attend testing at the specific times to

155 maintain circadian rhythmicity and were withdrawn from further involvement. In total,
156 the completion rate of the study was 85.7% with 36 completed participants' data used
157 for further analysis.

158

159 *Procedures*

160 *Warm up*

161 A standardized warm-up comprising five minutes of easy jogging followed by
162 dynamic preparatory movements such as squatting and lunging was undertaken by all
163 participants before isometric and 1RM squat testing. In preparation for isometric squat
164 tests, participants completed warm-up repetitions at self-determined estimated 75%
165 and 90% of maximal effort prior to maximal testing. Prior to maximal 1RM squat
166 efforts to ninety degrees of knee flexion angle, participants completed 3 repetitions at
167 50%, 2 at 80%, and 1 at 90% of self-estimated 1RM.

168

169 *Isometric squat*

170 Isometric squat was assessed at a knee angle of 90° (IS⁹⁰) using a custom isometric
171 rack (Samson Equipment Inc, NM, USA) with adjustable settings to the nearest 2.5
172 cm of vertical displacement. The knee angle was chosen as this approximately reflects
173 the sticking point during the squat exercise (Bazyler, Sato, Wassinger, Lamont, &
174 Stone, 2014). All participants performed the test at the same relative knee angle,
175 measured using a handheld goniometer (66fit Ltd Lincolnshire, UK) by the lead
176 investigator. The isometric rack was positioned directly over two force plates (Kistler
177 type 9286BA, Winterthur, Switzerland) connected to an A/D converter (Kistler type
178 5691A1, Winterthur, Switzerland). The desired position for testing required
179 participants to stand on the force plate with their feet approximately shoulder width

180 apart, trunk near-vertical, and the immoveable horizontal bar placed above the
181 posterior deltoids at the base of the neck. This position was established before each
182 trial, with the joint angle confirmed using goniometry. Participants' stance widths
183 were monitored using a standard measuring tape to ensure consistency between trials.
184 Participants were advised to maintain a constant and minimal pre-tension until the
185 tester gave verbal instruction, "2, 1, GO" upon which participants were cued to "push
186 against the ground as hard and as fast as possible". This external focus of attention has
187 previously been reported to optimize peak force output (Halperin, Williams, Martin,
188 & Chapman, 2016). All participants were given verbal encouragement during each
189 trial. Temporal and vertical ground reaction force (F_z) data were collected at a
190 sampling frequency of 1000 Hz for a five second sampling period using Bioware®
191 software (Version 5.1, Type 2812A). Trials were terminated when a plateau in the
192 force time trace was visually observed (Bazyler et al., 2014). The force plate was
193 zeroed immediately before each trial and sampling began on the verbal command.
194 Each participant completed two maximal effort trials with three minutes of passive
195 rest in between with the average of both trials used for further analysis.

196

197 *1RM squat*

198 The 1RM squat to a knee flexion angle of 90° was performed according to the exercise
199 technique outlined by Chandler (1991) using a standard 20 kg Olympic barbell and
200 plates (Eleiko AB, Halmstad, Sweden) for loading. Participants were instructed to
201 adopt a shoulder width stance in keeping with their normal squat stance, descend in a
202 controlled manner, avoid bouncing at the bottom position, maintain as near a vertical
203 torso as possible and feet always flat on the ground. Each 1RM trial was performed to
204 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

230 (ICC; 3,1) and their 95% confidence intervals (CI), standard error of measurement
 231 (SEM), and coefficient of variation (CV) were calculated on test-retest data. ICC was
 232 interpreted using the criteria of Cortina (1993), whereby $ICC \geq 0.80$ is highly reliable.
 233 SDD was calculated to enable interpretation of performance change over time for this
 234 test. The equations used within this study were; $SEM = SD \times \sqrt{1 - ICC}$,
 235 $SDD = 1.96 \times \sqrt{2} \times SEM$ (Beckerman et al., 2001; Weir, 2005). A general linear
 236 model repeated measures ANOVA was used to examine the impact of familiarization
 237 on kinetic performance variables across the five testing sessions. Mauchly's test of
 238 sphericity was applied and if violated, the Greenhouse-Geisser correction factor was
 239 used. Where appropriate, post-hoc analyses of significant effects were performed
 240 using the Huynh-Feldt correction method. Independent t tests were used to assess the
 241 difference between strong and weak groups, determined by percentile division of the
 242 total sampled participants. Strong participants were identified as the top 25% with
 243 weaker participants defined within the bottom 25% (Bailey et al., 2015a; Bailey, Sato,
 244 Burnett, & Stone, 2015b). This approach was repeated for IS^{90} peak, net and relative
 245 force variables independently as participants may have a high level of absolute
 246 strength but not necessarily a high level of relative strength due to effects of body mass
 247 (Folland, Mc Cauley, & Williams, 2008). Effect size (ES) was calculated by dividing
 248 the between group difference by the pooled standard deviation to determine the
 249 magnitude of difference between groups and classified as trivial (< 0.2), small ($0.2 -$
 250 0.6), moderate ($0.6 - 1.2$), large ($1.2 - 2.0$), and very large ($2.0 - 4.0$) (Hopkins,
 251 Marshall, Batterham, & Hanin, 2009). Statistical significance was set at $P \leq 0.05$.
 252 Pearson's correlation assessed the relationship between IS^{90} kinetic variables and 1RM
 253 squat performance using the previous discussed thresholds (Hopkins, 2002). All
 254 statistical calculations were performed using IBM SPSS Statistics 22 software (SPSS

255 Inc., Chicago, IL, USA).

256

257 **Results**

258 Shapiro-Wilk's test revealed all IS⁹⁰ & 1RM variables were normally distributed.

259 Repeated measures ANOVA showed that Mauchly's test of sphericity was violated

260 ($\chi^2(9) = 19.13, p = .24$; $\chi^2(9) = 19.34, p = .23$; $\chi^2(9) = 17.27, p = .45$) for IS⁹⁰ peak,

261 net and relative force variables respectively. Degrees of freedom were adjusted using

262 the Huynh-Feldt correction. A significant main effect was found across testing time

263 points, $F(3.68, 128.7) = 9.23, p < .001$. Bonferroni post hoc comparisons revealed

264 significant increases in peak force, net force and relative force between familiarization

265 1 to 3, and between familiarization 2 to 3 ($p \leq .002$). Non-significant differences were

266 found between familiarization 3 to test session, and between test to retest sessions.

267 Statistics provided in table 1 and figure 1.

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

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

270 Test-retest IS⁹⁰ force variables were highly reliable (ICC = .856 - .910, 95% CI [.735

271 to .953], CV = 3.78 - 6.11%). Standard error of measurement was 98.62N, 97.53N,

272 and 1.04N·kg⁻¹ for peak, net and relative IS⁹⁰ force variables respectively. Reliability

273 statistics provided in table 2.

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

275 Bland Altman analysis showed in test-retest conditions, IS⁹⁰ peak force had a bias of

276 -14.98N (precision -32.12 to 62.09; limits of agreement -257.93 to 287.9), IS⁹⁰ net

277 force had a bias of -14.08N (precision -32.64 to 60.81; limits of agreement -256.58 to

284.75) and IS⁹⁰ relative force had a bias of $-.161\text{N}\cdot\text{kg}^{-1}$ (precision $-.34$ to $.66$; limits of agreement -2.72 to 3.05). No proportional bias was detected for any of the IS⁹⁰ variables ($p = .757, .940$ and $.637$ for peak, net and relative force respectively).

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

IS⁹⁰ peak force demonstrated a significant large correlation with 1RM load. IS⁹⁰ net force demonstrated a significant large correlation with 1RM load, and significant moderate correlation with 1RM relative load. IS⁹⁰ 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 IS⁹⁰ peak force (Strong $\geq 2689\text{N}$; Weak $\leq 2276\text{N}$), 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 IS⁹⁰ net force (Strong $\geq 1771\text{N}$; Weak $\leq 1365\text{N}$), 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 IS⁹⁰ relative force (Strong $\geq 29.6\text{N}\cdot\text{kg}^{-1}$; Weak $\leq 24.1\text{N}\cdot\text{kg}^{-1}$), 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.

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

303 **Discussion**

304 This study aimed to assess the stability reliability of the IS⁹⁰ test having accounted for
305 familiarization. Calder and Gabriel (2007) suggest that intentional or unintentional
306 effects of familiarization are important to consider when interpreting studies assessing
307 reliability and responsiveness. Changes in force output during familiarization can be
308 influenced by multiple factors beyond true changes in muscle strength, such as
309 learning execution technique, tolerance of maximal loads, increased motor unit
310 recruitment (Amarante do Nascimento et al., 2013) and decreases in antagonist co-
311 contraction (Calder & Gabriel, 2007). Notably, this study found participants with an
312 average strength training experience of 4.1 years required three familiarization
313 sessions prior to stabilization of effects. Prior investigations using isometric multi-
314 joint tests report a familiarization was undertaken before testing but neglect to
315 demonstrate the stabilization of learning effects prior to the assessment of reliability
316 (Bazylar et al., 2014; Haff, Ruben, Lider, Twine, & Cormie, 2015). As such, observed
317 learning effects within this study are not comparable to previous studies although they
318 may be generalizable to similar strength trained populations. However, familiarization
319 effects during a 1RM squat test were found to stabilize after approximately three
320 sessions (Soares-Caldeira et al., 2009), corroborating with the findings in this study.

321

322 Very high to nearly perfect relative reliability was found for IS⁹⁰ variables between
323 test and retest sessions. No systematic bias was found between test-retest sessions with
324 Bland-Altman analysis revealing no proportional bias exists between measures.
325 Stability reliability measures within this study are congruent with resistance strength
326 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 IS⁹⁰ 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 IS⁹⁰ as a reliable monitoring tool, which is a key requirement to monitor training effects over time (Atkinson & Nevill, 1998).

340

The SDD was determined as 274 N, 270 N, and 2.9 N·kg⁻¹ for IS⁹⁰ 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

352 studies with comparable populations.

353

354 Results showed 1RM load has a significant correlation with IS⁹⁰ peak force ($r = .688$)
355 and IS⁹⁰ net force ($r = .616$). 1RM relative load has a significant correlation with IS⁹⁰
356 relative force ($r = .759$) and significant correlation IS⁹⁰ net force ($r = .419$). The
357 strength of these relationships corroborates with previous reported correlations
358 between isometric squats with 1RM squat. Nuzzo, McBride, Cormie, and McCaulley
359 (2008) found large significant correlation ($r = .624$) between IS^{140 knee} and 1RM^{70 knee},
360 with Blazeovich, Gill, and Newton (2002) showing similar very large significant
361 correlation ($r = .77$) between IS^{90 knee} and 1RM^{110 knee}. Bazyler et al. (2014)
362 demonstrated the effects of joint angle on the corresponding relationship with the 1RM
363 performance, where IS^{90 knee} has a very large relationship ($r = .864$) with 1RM back
364 squat and IS^{120 knee} has a moderate relationship ($r = .597$). Such findings illustrate the
365 importance of testing angle selection and explains a proportion of variation amongst
366 correlational statistics between 1RM and IMJTs.

367

368 Strength of correlations between 1RM squat and isometric squat will largely be
369 affected by the technical skill and experience of the participants (Abernethy, Wilson,
370 & Logan, 1995), as well as the utilization of the strength shortening cycle to contribute
371 to force expression in the 1RM (Baker, Wilson, & Carlyon, 1994). It is therefore
372 unlikely a perfect correlation will exist between 1RM squat and isometric squat,
373 although we surmise that the concentric contraction force capacity would be nearly
374 perfectly correlated with isometric contraction force. Monitoring of concentric
375 contraction velocity within this study verified 1RM efforts were truly maximal (0.294
376 ± 0.086 m/s for participants last successful effort) in corroboration with existing

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

377 evidence (Loturco et al., 2016), allowing future comparisons to be made. The large to
378 very large correlations observed between IS⁹⁰ and 1RM performance observed in this
379 study and consistently in other published work demonstrates appropriate criterion
380 validity for the IS⁹⁰ to be used to evaluate strength performance instead of 1RM testing.
381 We subscribe to the viewpoint that testing angle is important to correspond to the range
382 of motion of the training exercise and the portion of the exercise where the sticking
383 region occurs (Blazevich et al., 2002).
384
385 Significantly higher isometric strength corresponds to greater jump performance
386 (Kraska et al., 2009; Secomb et al., 2016) and cycling performance (Stone et al., 2004)
387 compared to weaker participants. Thomas, Jones, et al. (2015) suggested that it is
388 unknown whether significant differences in relative isometric strength measurements
389 would transfer to relative dynamic strength, such as the 1RM back squat. In this study,
390 between group analysis showed IS⁹⁰ net force and relative force capacity successfully
391 discriminated between 1RM and relative 1RM performance. Furthermore, IS⁹⁰ peak
392 force discriminated between 1RM load but not relative 1RM performance. These
393 results confirm that isometric relative strength does transfer as relative dynamic
394 strength in the population studied in this investigation. Overall, our findings support
395 the use of the IS⁹⁰ as a valid tool for assessing strength capacity and present a case that
396 IS⁹⁰ does discriminate between dynamic strength capacity. With very large
397 relationships reported between IMJTs and 1RM performance (McGuigan, Winchester,
398 & Erickson, 2006), Blazevich et al. (2002) reports IMJT measures could be used to
399 predict 1RM performance therefore enabling estimated training loads for dynamic
400 exercises. Research pertaining to predictive approaches may find strongest validity in

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

401 isometric net and relative variables as these have discriminated most clearly within
402 this study between 1RM performance.

404 **Conclusion**

405 To achieve reliable isometric strength data, pre-testing practice sessions are required
406 to account for the effects of familiarization. Isometric squats require less repetitions
407 or time comparatively to traditional 1RM testing which enhances practicality and
408 implementation into athlete's schedules. Under test retest conditions this study has
409 demonstrated that the IS⁹⁰ is highly reliable. When evaluating strength trained athletes,
410 11% increases in peak or relative force represent meaningful differences beyond the
411 error of the test. IS⁹⁰ discriminates between strong and weak performers in the 1RM
412 squat and therefore can be used as an alternative method of evaluating strength beyond
413 the conventional 1RM method.

415 **References**

- 416 Abernethy, P., Wilson, G., & Logan, P. (1995). Strength and power assessment -
417 issues, controversies and challenges. *Sports Medicine*, 19(6), 401-417.
- 418 Amarante do Nascimento, M., Januario, R. S. B., Gerage, A. M., Mayhew, J. L.,
419 Pina, F. L. C., & Cyrino, E. S. (2013). Familiarization and Reliability of One
420 Repetition Maximum Strength Testing in Older Women. *Journal of Strength*
421 *and Conditioning Research*, 27(6), 1636-1642.
- 422 Appleby, B., Newton, R. U., & Cormie, P. (2012). Changes in strength over a 2-year
423 period in professional rugby union players. *Journal of strength and*
424 *conditioning research*, 26(9), 2538-2546.

- Atkinson, G., & Nevill, A. M. (1998). Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. *Sports Medicine*, 26(4), 217-238.
- Bailey, C. A., Sato, K., Burnett, A., & Stone, M. H. (2015a). Carry-over of force production symmetry in athletes of differing strength levels. *Journal of Strength and Conditioning Research*, 29(11), 3188-3196.
- Bailey, C. A., Sato, K., Burnett, A., & Stone, M. H. (2015b). Force-Production Asymmetry in Male and Female Athletes of Differing Strength Levels. *International Journal of Sports Physiology and Performance*, 10(4), 504-508.
- Baker, D., Wilson, G., & Carlyon, B. (1994). Generality versus specificity - a comparison of dynamic and isometric measures of strength and speed-strength. *European Journal of Applied Physiology and Occupational Physiology*, 68(4), 350-355.
- Banyard, H. G., Nosaka, K., & Haff, G. G. (2017). Reliability and Validity of the Load–Velocity Relationship to Predict the 1RM Back Squat. *Journal of Strength & Conditioning Research*, 31(7), 1897–1904.
- Baumgartner, T. A. (1989). Norm-referenced measurement: reliability. . In M. J. Safrit & T. M. Wood (Eds.), *Measurement concepts in physical education and exercise science*. Champaign, IL: Human Kinetics.
- Bazyler, C. D., Beckham, G. K., & Sato, K. (2015). The use of the isometric squat as a measure of strength and explosiveness. *Journal of Strength and Conditioning Research*, 29(5), 1386-1392.
- Bazyler, C. D., Sato, K., Wassinger, C. A., Lamont, H. S., & Stone, M. H. (2014). The efficacy of incorporating partial squats in maximal strength training. *Journal of Strength and Conditioning Research*, 28(11), 3024-3032.

- 450 Beckerman, H., Roebroek, M. E., Lankhorst, G. J., Becher, J. G., Bezemer, P. D., &
451 Verbeek, A. L. M. (2001). Smallest real difference, a link between
452 reproducibility and responsiveness. *Quality of Life Research*, 10(7), 571-578.
- 453 Bland, J. M., & Altman, D. G. (1986). Statistical methods for assessing agreement
454 between two methods of clinical measurement. *Lancet*, 1(8476), 307-310.
- 455 Blazeovich, A. J., Gill, N., & Newton, R. U. (2002). Reliability and validity of two
456 isometric squat tests. *Journal of Strength and Conditioning Research*, 16(2),
457 298-304.
- 458 Brady, C. J., Harrison, A. J., Flanagan, E. P., Haff, G. G., & Comyns, T. M. (2017).
459 A Comparison of the Isometric Mid-Thigh Pull and Isometric Squat: Intraday
460 Reliability, Usefulness and the Magnitude of Difference Between Tests. *Int*,
461 *J. Sports Physiol Perform*, Advance online publication. doi:
462 10.1123/ijsp.2017-0480.
- 463 Buckner, S. L., Jessee, M. B., Mattocks, K. T., Mouser, J. G., Counts, B. R., Dankel,
464 S. J., & Loenneke, J. P. (2016). Determining strength: A case for multiple
465 methods of measurement. *Sports Medicine*, 1-3.
- 466 Calder, K. M., & Gabriel, D. A. (2007). Adaptations during familiarization to
467 resistive exercise. *Journal of Electromyography and Kinesiology*, 17(3), 328-
468 335.
- 469 Chandler, T., J. & Stone, M., H. (1991). The Squat Exercise in Athletic
470 Conditioning: A Position Statement and Review of the Literature. *Strength*
471 *and Conditioning Journal*, 13(5), 51-58.
- 472 Charles, P., Giraudeau, B., Dechartres, A., Baron, G., & Ravaud, P. (2009).
473 Reporting of sample size calculation in randomised controlled trials: review.
474 *BMJ*, 338.

- 1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65
- 475 Comfort, P., Jones, P. A., McMahon, J. J., & Newton, R. (2015). Effect of knee and
476 trunk angle on kinetic variables during the isometric midthigh pull: test-retest
477 reliability. *Int J Sports Physiol Perform*, 10(1), 58-63.
- 478 Comfort, P., & McMahon, J. J. (2015). Reliability of Maximal Back Squat and
479 Power Clean Performances in Inexperienced Athletes. *J. Strength Cond Res*,
480 29(11), 3089–3096.
- 481 Cortina, J. M. (1993). What is coefficient alpha? An examination of theory and
482 applications. *Journal of Applied Psychology*, 78(1), 98.
- 483 Davidson, M., & Keating, J. (2014). Patient-reported outcome measures (PROMs):
484 how should I interpret reports of measurement properties? A practical guide
485 for clinicians and researchers who are not biostatisticians. *British Journal of*
486 *Sports Medicine*, 48(9), 792-796.
- 487 Dos'Santos, T., Thomas, C., Comfort, P., McMahon, J.J., Jones, P.A., & Oakley, N.
488 P., Young, A.L. (2017). Between-Session Reliability Of Isometric Mid-Thigh
489 Pull Kinetics And Maximal Power Clean Performance In Male Youth Soccer
490 Players. *Journal of strength and conditioning research*, Advance online
491 publication. doi: 10.1519/JSC.0000000000001830.
- 492 Drake, D., Kennedy, R., & Wallace, E. (2017). The Validity and Responsiveness of
493 Isometric Lower Body Multi-Joint Tests of Muscular Strength: a Systematic
494 Review. *Sports Medicine - Open*, 3(1), 23.
- 495 Faul, F., Erdfelder, E., Buchner, A., & Lang, A.-G. (2009). Statistical power
496 analyses using G* Power 3.1: Tests for correlation and regression analyses.
497 *Behavior research methods*, 41(4), 1149-1160.
- 498 Folland, J. P., Mc Cauley, T. M., & Williams, A. G. (2008). Allometric scaling of
499 strength measurements to body size. *Eur J Appl Physiol*, 102(6), 739-745.

- 500 Haff, G. G., Ruben, R. P., Lider, J., Twine, C., & Cormie, P. (2015). A comparison
501 of methods for determining the rate of force development during isometric
502 midhigh clean pulls. *Journal of strength and conditioning research*, 29(2),
503 386-395.
- 504 Halperin, I., Williams, K. J., Martin, D. T., & Chapman, D. W. (2016). The effects of
505 attentional focusing instructions on force production during the isometric
506 midhigh pull. *Journal of Strength and Conditioning Research*, 30(4), 919-
507 923.
- 508 Hopkins, W. G. (2002). *A new view of statistics*, [Retrieved from:
509 <http://sportsci.org/resource/stats/effectmag.html>].
- 510 Hopkins, W. G. (2004). How to interpret changes in an athletic performance test.
511 *Sportscience*, 8(1), 1-7.
- 512 Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive
513 statistics for studies in sports medicine and exercise science. *Medicine and*
514 *Science in Sports and Exercise*, 41(1), 3-12.
- 515 Jidovtseff, B., Harris, N. K., Crielaard, J. M., & Cronin, J. B. (2011). Using the load-
516 velocity relationship for 1RM prediction. *Journal of Strength and*
517 *Conditioning Research*, 25(1), 267-270.
- 518 Kennedy, R. A., & Drake, D. (2017). Dissociated time course of recovery between
519 strength and power after isoinertial resistance loading in rugby union players.
520 *Journal of Strength and Conditioning Research*, Advance online publication.
521 doi: 10.1519/JSC.0000000000001821.
- 522 Kraska, J. M., Ramsey, M. W., Haff, G. G., Fethke, N., Sands, W. A., Stone, M. E.,
523 & Stone, M. H. (2009). Relationship between strength characteristics and

524 unweighted and weighted vertical jump height. *Int J Sports Physiol Perform*,
 525 4(4), 461-473.
 526 Loturco, I., Pereira, L., Abad, C. C. C., Gil, S., Kitamura, K., Kobal, R., &
 527 Nakamura, F. Y. (2016). Using bar velocity to predict the maximum dynamic
 528 strength in the half-squat exercise. *Int J. Sports Physiol Perform*, 11(5), 697-
 529 700.
 530 Maffiuletti, N. A., Aagaard, P., Blazevich, A. J., Folland, J., Tillin, N., & Duchateau,
 531 J. (2016). Rate of force development: physiological and methodological
 532 considerations. *European Journal of Applied Physiology*, 1-26.
 533 McGuigan, M. R., Newton, M. J., Winchester, J. B., & Nelson, A. G. (2010).
 534 Relationship between isometric and dynamic strength in recreationally
 535 trained men. *Journal of Strength and Conditioning Research*, 24(9), 2570-
 536 2573.
 537 McGuigan, M. R., Winchester, J. B., & Erickson, T. (2006). The importance of
 538 isometric maximum strength in college wrestlers. *Journal of Sports Science*
 539 *and Medicine*, 5, 108-113.
 540 McMaster, D. T., Gill, N., Cronin, J., & McGuigan, M. (2014). A brief review of
 541 strength and ballistic assessment methodologies in sport. *Sports Medicine*,
 542 44(5), 603-623.
 543 Nuzzo, J. L., McBride, J. M., Cormie, P., & McCaulley, G. O. (2008). Relationship
 544 between countermovement jump performance and multijoint isometric and
 545 dynamic tests of strength. *Journal of Strength and Conditioning Research*,
 546 22(3), 699-707.
 547 Palmer, T. B., Pineda, J. G., & Durham, R. M. (2017). Effects of Knee Position on
 548 the Reliability and Production of Maximal and Rapid Strength Characteristics

549 During an Isometric Squat Test. *Journal of Applied Biomechanics*, Advance
550 online publication. doi: 10.1123/jab.2017-0213.

551 Pereira, M. I. R., & Gomes, P. S. C. (2003). Muscular strength and endurance tests:
552 reliability and prediction of one repetition maximum-Review and new
553 evidences. *Revista Brasileira de Medicina do Esporte*, 9(5), 325-335.

554 Ploutz-Snyder, L. L., & Giamis, E. L. (2001). Orientation and familiarization to
555 1RM strength testing in old and young women. *Journal of Strength and*
556 *Conditioning Research*, 15(4), 519-523.

557 Ritti-Dias, R. M., Avelar, A., Salvador, E. P., & Cyrino, E. S. (2011). Influence of
558 previous experience on resistance training on reliability of one-repetition
559 maximum test. *Journal of Strength and Conditioning Research*, 25(5), 1418-
560 1422.

561 Sanchez-Medina, L., & Gonzalez-Badillo, J. J. (2011). Velocity loss as an indicator
562 of neuromuscular fatigue during resistance training. *Med Sci Sports Exerc*,
563 43(9), 1725-1734.

564 Secomb, J. L., Nimphius, S., Farley, O. R., Lundgren, L., Tran, T. T., & Sheppard, J.
565 M. (2016). Lower-Body Muscle Structure and Jump Performance of Stronger
566 and Weaker Surfing Athletes. *Int J Sports Physiol Perform*, 11(5), 652-657.

567 Soares-Caldeira, L. F., Ritti-Dias, R. M., Okuno, N. M., Cyrino, E. S., Gurjao, A. L.
568 D., & Ploutz-Snyder, L. L. (2009). Familiarization indexes in sessions of 1-
569 RM tests in adult women. *Journal of Strength and Conditioning Research*,
570 23(7), 2039-2045.

571 Stone, M. H., Sands, W. A., Carlock, J., Callan, S., Dickie, D., Daigle, K., . . .
572 Hartman, M. (2004). The importance of isometric maximum strength and

573 peak rate of force development in sprint cycling. *Journal of Strength and*
574 *Conditioning Research*, 18(4), 878-884.

575 Storey, A., Wong, S., Smith, H. K., & Marshall, P. (2012). Divergent muscle
576 functional and architectural responses to two successive high intensity
577 resistance exercise sessions in competitive weightlifters and resistance
578 trained adults. *European Journal of Applied Physiology*, 112(10), 3629-3639.

579 Suchomel, T. J., Nimphius, S., & Stone, M. H. (2016). The importance of muscular
580 strength in athletic performance. *Sports Medicine*, 46(10), 1419-1449.

581 Taylor, K.-L., Cronin, J., Gill, N. D., Chapman, D. W., & Sheppard, J. (2010).
582 Sources of Variability in Iso-Inertial Jump Assessments. *International*
583 *Journal of Sports Physiology & Performance*, 5(4), 546-558.

584 Teo, W. P., McGuigan, M. R., & Newton, M. J. (2011). The effects of circadian
585 rhythmicity of salivary cortisol and testosterone on maximal isometric force,
586 maximal dynamic force, and power output. . *Journal of Strength and*
587 *Conditioning Research*, 25(6), 1538-1545.

588 Terwee, C. B., Bot, S. D. M., de Boer, M. R., van der Windt, D. A. W. M., Knol, D.
589 L., Dekker, J., . . . de Vet, H. C. W. (2007). Quality criteria were proposed
590 for measurement properties of health status questionnaires. *Journal of*
591 *Clinical Epidemiology*, 60(1), 34-42.

592 Thomas, C., Comfort, P., Chiang, C., & Jones, P. A. (2015). Relationship between
593 isometric mid thigh pull variables and sprint and change of direction
594 performance in collegiate athletes. *Journal of Trainology*, 4(1), 6-10.

595 Thomas, C., Dos'Santos, T., Comfort, P., & Jones, A. P. (2017). Between-session
596 reliability of common strength and power related measures in adolescent
597 athletes. *Sports*, 5(1).

598 Thomas, C., Jones, P. A., Rothwell, J., Chiang, C. Y., & Comfort, P. (2015). An
 599 investigation into the relationship between maximum isometric strength and
 600 vertical jump performance. *Journal of Strength and Conditioning Research*,
 601 29(8), 2176-2185.
 602 Wang, R., Hoffman, J. R., Tanigawa, S., Miramonti, A. A., La Monica, M. B.,
 603 Beyer, K. S., . . . Jeffrey, S. R. (2016). Isometric mid-thigh pull correlates
 604 with strength, sprint and agility performance in collegiate rugby union
 605 players. *Journal of Strength and Conditioning Research*, 30(11), 3051-3056.
 606 Weir, J. P. (2005). Quantifying test-retest reliability using the intraclass correlation
 607 coefficient and the SEM. *Journal of Strength and Conditioning Research*,
 608 19(1), 231-240.

617 **Figure 1.**

618 Box plot for IS⁹⁰ peak force across testing sessions.

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

622 **Figure 2.**

623 Bland Altman plot for IS⁹⁰ Peak Force. Solid line represents the mean difference;
624 dashed lines represent 95% limits of agreement.

625

626 **Figure 3.**

627 Bland Altman plot for IS⁹⁰ Net Force. Solid line represents the mean difference;
628 dashed lines represent 95% limits of agreement.

629

630 **Figure 4.**

631 Bland Altman plot for IS⁹⁰ Relative Force. Solid line represents the mean difference;
632 dashed lines represent 95% limits of agreement.

633

634

635

TABLE 1. Effects of familiarization on force variables

Test session	Familiariza tion 1 - 2	Familiariza tion 2 - 3	Familiariza tion 3 - Test	Test - Retest
Δ IS⁹⁰ Peak force (N)	45.61	91.15*	-38.42	-14.98
SD	145.5	133.1	138.7	139.2
<i>p</i>	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 IS⁹⁰ Net force (N)	45.34	92.19*	-39.94	-14.08
SD	145.9	131.0	138.0	138.1
<i>p</i>	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 IS⁹⁰ Relative force (N·kg⁻¹)	0.536	1.03*	-0.433	-0.161
SD	1.69	1.48	1.53	1.47
<i>p</i>	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·kg⁻¹ = newton per kilogram of body mass; SD = standard deviation; CV = coefficient of variation

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·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·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. 1RM performance comparison based on IS⁹⁰ determined strong and weak groups

Grouping variable	IS ⁹⁰ Peak force (N)		IS ⁹⁰ Net force (N)		IS ⁹⁰ Relative force (N·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
<i>p</i>	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·kg⁻¹ = newton per kilogram of body mass; Strong and weak group data are presented as means ± SD.

Figure 1.

Box plot for IS⁹⁰ 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 IS⁹⁰ Peak Force. Solid line represents the mean difference; dashed lines represent 95% limits of agreement.

Figure 3.

Bland Altman plot for IS⁹⁰ Net Force. Solid line represents the mean difference; dashed lines represent 95% limits of agreement.

Figure 4.

Bland Altman plot for IS⁹⁰ Relative Force. Solid line represents the mean difference; dashed lines represent 95% limits of agreement.