

1 **Reliability, familiarisation effect and comparisons between a pre-**
2 **determined and a self-determined isometric squat testing protocol**

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16 **SUBMISSION TYPE:** Original Investigation.

17 **PREFERRED RUNNING HEAD:** Isometric squat reliability and familiarisation.

18

19

20 Abstract

21 **Purpose:** This study examined the inter-day reliability of a pre-determined (PDet) or a self-
22 determined (SDet) isometric squat test (ISqT) among youth soccer players. Familiarisation
23 effects were evaluated to determine the minimum number of trials necessary to obtain
24 consistent outputs. Lastly, protocol differences were evaluated. **Methods:** Thirty-one youth
25 soccer players (mean \pm SD: age: 13.2 ± 1.0 years; body mass: 54.1 ± 3.4 kg; stature: $166.3 \pm$
26 11.2 cm; percentage of estimated adult height: $92.6 \pm 3.6\%$) from a top tier professional
27 academy completed four experimental sessions for each protocol: familiarisation 1,
28 familiarisation 2, test, and retest sessions. Peak force (PF), relative peak force (rPF), impulse
29 from 0-50ms (IMP50), 0-100ms (IMP100), 0-150ms (IMP150), and 0-200ms (IMP200), and
30 rate of force development from 0-50ms (RFD50), 0-100ms (RFD100), 0-150ms (RFD150),
31 and 0-200ms (RFD200) were measured. **Results:** Both protocols displayed acceptable
32 (intraclass correlation coefficient ≥ 0.75 and coefficient of variation $\leq 10\%$) reliability statistics
33 for all metrics apart from RFD of any time epoch. Differences were found between
34 familiarisation 2 and both test and retest sessions for PF ($P = 0.034$ and 0.021 respectively) and
35 rPF ($P = 0.035$ and 0.005 respectively) across both protocols. **Conclusions:** The ISqT is a
36 reliable test among youth soccer players. Two familiarisation sessions seem to be sufficient to
37 ensure data stabilisation. Outputs between the SDet and PDet are comparable, however, the
38 latter seems preferable due to improved testing time efficiency.

39

40 Key Words: Strength, power, assessment, self-determination, autonomy

41 INTRODUCTION

42 Accurate measurement of force production capabilities is paramount for practitioners,
43 particularly those working with developing athletes, to prescribe, monitor and evaluate training
44 programming given the importance of muscular strength and power as athletes transition
45 towards the elite level ¹.

46 Isometric assessments, such as the isometric squat (ISqT) or mid-thigh pull (IMTP) tests, are
47 time-effective, reliable, and are associated to a low injury risk ^{2,3}. Reliability is a crucial element
48 to effectively delineate training adaptations from measurement variability and accurately
49 determine true performance changes over time. However, no reliability evidence is available
50 among youth cohorts for the ISqT ². Familiarisation, rather than physiological adaptation, can
51 affect force production capacity when athletes are repeatedly tested in quick succession,
52 thereby also impacting reliability ^{4,5}.

53 Time management is a challenge for applied practitioners or those working with large groups,
54 as they may be unable to carry out isometric assessments due to the time-consuming procedures
55 associated with the recommendations of specific body configurations ⁶. An alternative to pre-
56 determined (PDet) protocols is the use of self-determined (SDet) protocols, where athletes can
57 choose their body configuration ^{7,8}. Previous research found no differences between a PDet and
58 a SDet protocol for the IMTP ⁷. However, empirical evidence is lacking with regard to
59 reliability of a SDet ISqT protocol among youth, the minimum number of sessions required for
60 data to stabilise, and differences between PDet and SDet protocols. Therefore, the aims of the
61 current investigation were to: 1) Determine the inter-day reliability of the ISqT in well trained
62 (i.e., ~6 training sessions per training week) youth soccer players; 2) Investigate the
63 familiarisation effects on ISqT outputs; and, 3) Compare PDet and a SDet ISqT outputs.

64

65 METHODS

66 SUBJECTS

67 A priori power analysis using G*Power (Universität Düsseldorf, Düsseldorf, Germany)
68 determined that a minimum of 17 participants would be required to detect a large correlation
69 of $r = 0.7$ among repeated measures with 80% power and an alpha of 5% for a correlational
70 design study. However, this sample size was superseded by the requirement of 28 participants
71 for the repeated measures design used to investigate familiarization effects and compare the

72 mechanical outputs between the PDet and a SDet protocol. A conservative correlation of 0.7
73 was chosen following pilot testing, where a minimum correlation coefficient equal to $r = 0.9$
74 was observed for peak force (PF) values. Therefore, 31 well-trained male youth soccer players
75 (mean \pm SD: age: 13.2 ± 1.0 years; body mass: 54.1 ± 3.4 kg; stature: 166.3 ± 11.2 cm;
76 percentage of estimated adult height (%EAH): $92.6 \pm 3.6\%$) participated in this study. %EAH
77 was determined using equations specific to European males chronological age based off mid-
78 parent height⁹, which was adjusted for overestimation¹⁰. Participants self-reported an average
79 of 2.0 ± 0.9 years of strength, weight or gym training, including 6 months of supervised training
80 which did not include back squat technique training. This investigation was conducted in
81 accordance with the Declaration of Helsinki and approved by an institutional Ethics Board
82 prior to data collection.

83

84 DESIGN

85 A repeated-measures design was used to determine the inter-day reliability and compare force-
86 time characteristics between two ISqT protocols in youth soccer players. Reliability was
87 assessed over a 6-week period in a stepwise, randomised and counter-balanced manner (Figure
88 1) during which each participant completed four sessions per protocol. Participants completed
89 one unmeasured familiarisation session, a second measured familiarisation session, followed
90 by a test and re-test sessions. Each testing session consisted of three trials of 3 second maximal
91 isometric effort separated by at least 2 minutes of rest. 3s efforts were chosen following pilot
92 data (unpublished data) which indicated this to be sufficient in order for youth to generate
93 maximal force.

94

95 FIGURE 1 ABOUT HERE

96

97 METHODOLOGY

98 Testing sessions were completed across a period of 1-11 days. Prior to each testing session, a
99 warm-up consisting of dynamic squatting, mobility, glute bridging, and lunging activities
100 followed by three warm-up isometric squats at 60%, 70% and 80%⁵ of maximum perceived
101 effort was performed. Thereafter, the protocol was explained and coaching cues provided for

102 correct execution to ensure consistency of technique. The ISqT efforts were performed using
103 an isometric rack with adjustable bar height to the nearest 7 cm. Dual-force plates (VALD
104 Performance, ForceDecks, Queensland, Australia) were positioned below the bar within the
105 isometric rack and recorded ground reaction force (GRF) data at 1000Hz¹¹. Force plates were
106 zeroed before each isometric effort and body mass recorded whilst standing still prior to the
107 first isometric effort of each session.

108 Participants gripped the bar with equal spacing of hands from its centre while standing off the
109 force plates. Participants then stepped onto the force plates and assumed a squat position with
110 the bar placed above the posterior deltoids and ensured to maintain a neutral pelvis and spinal
111 alignment during each effort to mitigate injury risk and allow for effective transfer of force.
112 Participants then lightly pressed their shoulders against the bar ready to push as well as to
113 remove slack from the bar and minimise early compliance due to skeletal muscle compression
114 during the effort¹².

115 Participants held this position to obtain a steady weighing period for 1-3 seconds² prior to each
116 isometric effort, which was ensured by the researcher through inspection of the live force-time
117 trace. This method was chosen upon pilot sessions to obtain an accurate representation of force
118 applied while participants were ready to initiate the isometric effort to ensure no impact upon
119 time dependent metrics. Participants were instructed to “reset” if exerting variable force during
120 the weighing period.

121 Participants were instructed to push against the ground as hard and as fast as they could¹³
122 following the auditory cue “GO”⁵, as pilot data indicated this method obtained smoother rates
123 of force development following contraction onset compared to self-selected onsets
124 (unpublished data). Trials were stopped and discarded if a large (>50N) countermovement was
125 detected during the weighing period, or if pain was reported, or movement occurred.
126 Encouragement was provided during each effort and the child’s pose stretch was carried out
127 post-effort to alleviate any acute posterior lumbo-pelvic muscle tension. Feedback was
128 provided in “real-time” via a TV screen stationed in front of a customised rack (IndigoFitness,
129 Nuneaton, England) to ensure maximal effort^{14,15}. Participants were informed of their PF
130 output following each effort to promote motivation to perform^{15,16}. Kinetic performance was
131 assessed by the researcher¹² with feedback provided before and after each effort^{14,17,18}.

132

133 ***PRE-DETERMINED ISOMETRIC SQUAT PROCEDURES***

134 The PDet ISqT protocol was performed at a knee joint angle of 120-130°^{12,19,20}. A range was
135 utilised as opposed to a specific angle to reduce testing time. Knee joint angle was confirmed
136 prior to each testing session using manual goniometry (66fit, Merseyside, England) and
137 corresponding to a specific bar height for each individual. Stance widths were monitored and
138 standardised for each PDet testing session with reference marks written on disposable tape
139 placed on the force plates.

140

141 ***SELF-DETERMINED ISOMETRIC SQUAT PROCEDURES***

142 Participants autonomously selected the SDet body configuration. Prior to body mass
143 measurement, participants stood on the force plates with a dowel rod on their shoulders,
144 replicating bar position. Participants then squatted down slowly to a position they felt
145 comfortable to push as hard and fast as they could against the floor. The nearest bar height on
146 the rig was noted and used for each trial during that session. Stance width, knee angle and bar
147 height were recorded during the weighing period prior to the first isometric effort of each
148 session.

149

150 ***ISOMETRIC SQUAT FORCE-TIME DATA ASSESSMENT***

151 Data recorded during each effort was calculated automatically (VALD Performance,
152 ForceDecks, Queensland, Australia). Contraction onset was defined as the first instantaneous
153 force rise $\geq 20\text{N}$ above the value of the weighing period and was confirmed as the true onset
154 prior to final analysis. Maximum force generated during effort was defined as PF, with the
155 maximum from session retained for further analysis. Relative PF (rPF) was obtained using ratio
156 scaling (PF/body mass). Additional metrics included impulse (IMP) and rate of force
157 development (RFD). Epochs from contraction onset until 50ms, 100ms, 150ms and 250ms^{7,8}
158 have been selected to describe early and late stages of force output given the transferability of
159 different stages to different tasks^{12,21}.

160

161 ***SELF-REPORT MEASURES***

162 Perception of autonomy was evaluated using a modified Basic Psychological Needs in Exercise
163 Scale upon completion of each protocol²². A modified version was utilised due to the

164 potentially confusing wording of questions in this questionnaire for immature adolescent
 165 populations. Participants rated four questions using a Likert scale, ranging from 1 (“Strongly
 166 Disagree”) to 5 (“Strongly Agree”). The questions were: “1. The testing programme I just
 167 participated in is the same as how I would like to train/ be tested in the future”, “2. The way I
 168 was just tested is the way I want to be tested in the future”, “3. I feel I am able to decide how I
 169 am tested in the future”, and “4. Making choices about the exercise/activities I do is important
 170 to me”. This final question was added in order to ascertain participants’ feelings on the
 171 importance of autonomy over testing procedures.

172

173 **STATISTICAL ANALYSIS**

174 Body configuration measures were compared between protocols using a one-sample t-test
 175 using the mean values of the PDet condition as critical value of the null-hypothesis testing
 176 given the consistency of the body configuration data in the PDet protocol. If assumption of
 177 normality was violated, a non-parametric Wilcoxon signed ranks test was used.

178 Hedges g effect sizes²³ were calculated to determine the magnitude of the differences in values
 179 between trials for both protocols and interpreted as described previously²⁴. In addition,
 180 percentage changes between testing sessions was also calculated for all force-time and body
 181 configuration metrics.

182 Intraclass correlation coefficients (ICC) and coefficient of variation (CV) and associated 95%
 183 confidence intervals (CI) were calculated to test inter-day reliability. An ICC lower than 0.5,
 184 between 0.5 and 0.75, between 0.75 and 0.9, and greater than 0.90 was interpreted as poor,
 185 moderate, good, and excellent relative reliability, respectively²⁵. A $CV \leq 10\%$ was deemed as
 186 acceptable absolute reliability²⁶. Reliability analysis was performed using customised
 187 spreadsheets²⁷.

188 The following linear mixed effects model was used to analyse effects of testing protocol on
 189 data across the three measured testing sessions:

$$190 \quad Y_i = \beta_0 + \beta_{1-3} \text{session number} + \beta_4 \text{protocol} + \varepsilon_i$$

191 The measured dependant variable (Y) for each observation (i ; participant) represents repeated
 192 measures for each subject, β_0 is the overall grand intercept and ε_i is the residual error (i.e.,
 193 unexplained variance) or the model. Predictor variables included: measurement session (β_{1-3} ;
 194 categorical variable with 3 levels [familiarisation session 2; test session, re-test session]) and
 195 protocol (β_4 ; categorical variable with 2 levels [PDet; SDet]). Moreover, random effects were

196 assumed for participants, training structures and exercise, with random slopes introduced in the
197 model if their addition did not result in a convergence error. Estimated marginal means and
198 95% confidence intervals were calculated alongside comparisons made using post-hoc Holm-
199 Bonferroni adjustments. Visual inspection of residual plots was used to confirm the
200 assumptions of homoscedasticity or normality, which was also assessed through the Shapiro-
201 Wilk test. Analysis was performed in R language and environment for statistical computing
202 using the lme4, lmerTest, emmeans, and ggeffects packages while model assumptions were
203 checked using the performance package (4.0.5; R Core Team, Vienna, Austria).

204

205 **RESULTS**

206 **PROTOCOL COMPARISONS**

207 Table 1 displays descriptive data of the participants average stance width, bar height, knee joint
208 angle and force at contraction onset for each protocol during testing sessions. Table 2 displays
209 body configuration and force-time metric percentage differences and effect sizes (Hedges' g)
210 between protocols. There were no significant differences for knee joint angle between the two
211 protocols ($p = 0.324$). There were significant differences between protocols for stance width,
212 bar height, and force at contraction onset (Tables 1 and 2). Table 3 displays the descriptive
213 statistics of the force-time variables across the familiarisation and experimental trials. With
214 significantly ($P = 0.048$) greater PF values observed in the SDet protocol compared to the PDet
215 protocol.

216

217 TABLE 1 ABOUT HERE

218

219 TABLE 2 ABOUT HERE

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221 TABLE 3 ABOUT HERE

222

223 **RELIABILITY**

224 Reliability statistics are displayed in Table 4. All metrics' average values displayed moderate
225 relative and acceptable reliability ($ICC \geq 0.75$ and $CV \leq 10\%$) except for IMP150 and IMP200
226 in the SDet protocol, and RFD measures in both protocols (Table 4).

227

228 TABLE 4 ABOUT HERE

229

230 **EFFECTS OF FAMILIARIZATION**

231 PF was significantly different between the familiarisation 2, test session ($P = 0.034$) and retest
232 session ($P = 0.021$) for both protocols, with no difference in familiarisation trends between
233 protocols ($P = 0.292$ and 0.431 respectively). With regards to rPF values, familiarisation 2
234 session outputs were significantly lower than both test ($P = 0.035$) and retest ($P = 0.005$)
235 session outputs with no significant interaction between session and protocol observed for any
236 testing session ($P = 0.612$ and 0.309 respectively). No other significant differences were
237 observed between testing sessions for any other metric ($P > 0.05$).

238

239 **SELF-REPORTED PERCEPTIONS OF AUTONOMY**

240 No differences were observed for any of the items of the autonomy questionnaire between the
241 two protocols ($X^2 [7] = 11.834, P = 0.106$).

242

243 **DISCUSSION**

244 The primary aim of this study was to establish the between-day reliability of force-time metrics
245 measured in the ISqT among adolescent soccer players. The secondary aim was to determine
246 the number of sessions required for data to stabilise. Finally, this investigation aimed to
247 compare PDet and SDet outputs. Average values obtained from ISqT displayed acceptable
248 reliability statistics among youth soccer players, however, the 95% CI often exceeded the
249 aforementioned reliability threshold ($ICC \geq 0.75$ and $CV \leq 10\%$). PF, rPF and IMP for any time
250 epoch demonstrated acceptable average reliability values for both protocols, whereas RFD was

251 deemed unacceptable regardless of the timeframe analysed (Table 4). PF outputs produced
252 during the SDet protocol were significantly larger compared to the PDet protocol, with no other
253 differences for any other mechanical measure between protocols (Table 3). Two familiarisation
254 sessions consisting of three trials are sufficient to when utilising an ISqT with youth athletes,
255 regardless of the protocol employed (Table 3).

256 In agreement with previous literature, PF displayed excellent^{12,19,28} and good⁵ average relative
257 reliability for the PDet and SDet protocols, respectively (Table 4). In addition, average rPF also
258 displayed good reliability for the SDet protocol, but moderate reliability for the PDet protocol
259 (Table 4). Drake *et al.*²⁹ reported excellent between-day test reliability for rPF (ICC: 0.92 and
260 CV: 5%) when utilising a PDet body position in the ISqT. This maybe as a result of a change
261 in the participants rank order as highlighted by the large 95% CIs of the ICC compared to that
262 of the CV (Table 4). Indeed, differing rates of isometric data stabilisation in youth compared
263 to adults may contribute to such a result³⁰. Therefore, the rPF metric may be slightly less
264 reliable when measured in youth compared to adult participants.

265 In agreement with previous research^{19,31} acceptable reliability (ICC ≥ 0.75 and CV $\leq 10\%$) was
266 observed for IMP across all time epochs regardless of protocol (Table 4). However, RFD
267 metrics were mostly unreliable regardless of time epoch or protocol (Table 4). Drake, Kennedy
268 and Wallace²⁹ found unreliable RFD reliability statistics irrespective of the time epoch (up to
269 0-250ms) analysed. Similarly, research reporting CVs across multiple time epochs highlighted
270 variability of 19.9-89.1% in adult participants²⁹ and unacceptable (CV: 16.8%) statistics for
271 the IMTP in adolescent athletes⁸. Therefore, RFD obtained from multi-joint isometric tests is
272 likely an unreliable metric to use with youth.

273 ISqT force-time outputs stabilized after two sessions consisting of three trials each (Table 3).
274 This is in contrast to Drake, Kennedy and Wallace⁵, who reported stable PDet ISqT force-time
275 characteristics after three familiarisation sessions. A potential reason explaining this finding
276 were the different participants' characteristics. While the current study involved youth soccer
277 players with a strength training experience of 2.0 ± 0.9 years, Drake Kennedy and Wallace⁵
278 investigated strength trained (training experience: 4.1 ± 1.8 years) adult males (age: 21.4 ± 4.5
279 years). Additionally, where the current investigation utilised the maximum PF value, Drake
280 Kennedy and Wallace⁵ used the average between trials, confounding comparisons between
281 studies. PF was found as stable over four weeks when testing IMTP in youth soccer players³².

282 Therefore, six familiarisation trials are likely required for ISqT data to stabilise regardless of
283 the protocol.

284 Albeit trivial, significant differences in PF were found between the PDet and SDet protocols
285 (Table 3). Moreover, a unimodal trend was found in favour of the SDet protocol, with all
286 mechanical outcomes being consistently greater in comparison with the PDet protocol.
287 Therefore, it appears that granting youth soccer players with choice over the body configuration
288 adopted during an ISqT result in greater values compared to a controlled approach. However,
289 given the differences in knee joint angle between protocols ($\sim 125 \pm 3^\circ$ vs $\sim 135 \pm 7^\circ$), it is
290 unclear whether this is due to mechanical mechanisms, psychological contributions, or
291 interactions between the two. Research should determine whether these differences persist
292 between protocols when both are performed at the same relative knee joint angle, thus
293 providing empirical insights regarding the underpinning mechanisms of force productions in
294 self-determined test protocols.

295 Interestingly, stance width displayed trivial changes between sessions while knee joint angle
296 displayed trivial-to-small changes between SDet sessions (Table 2). Similarly, participants
297 consistently chose comparable bar heights between the two sessions, with trivial differences
298 between sessions (Table 2), indicating youth soccer players can self-determine an ISqT set up
299 between testing sessions without any significant kinematic variability. This is a key finding, as
300 a SDet protocol may accommodate for changes in individual anthropometric characteristics
301 over prolonged periods of time. A SDet body position may be preferred by practitioners due to
302 the reduced time needed to carry out this protocol, similar familiarisation effect and greater
303 performance data when compare to that of a PDet protocol.

304 The current study is not without limitations. Participants in the current study are youth male
305 soccer players, which limits generalization to other cohorts. However, the PF outputs of the
306 current study were similar to those displayed by youth athletes from various sports³³. In
307 addition, generalisation to other isometric tests is not possible due to differences in body
308 configuration between tests. In addition, previous research has found reliable time-dependent
309 force-time metrics (e.g., RFD) through the use of ‘explosive’ 1 second protocols^{12,29}, therefore
310 it maybe that the protocol duration of the current study was not conducive to eliciting reliable
311 RFD outputs. However, the aforementioned protocol^{12,29} remains to be evaluated in youth. In
312 addition, due to the time commitment needed to carry out additional 1-second explosive
313 protocols with the requisite recovery period, this was not feasible in the current investigation.

314 Lastly, due to ecological logistic constraints within sporting environments, successive trials
315 were performed with more than a week apart for some participants. However, it is unlikely that
316 physiological changes contributing to strength and power improvements would have occurred
317 throughout this time period.

318

319 **PRACTICAL APPLICATIONS**

320 This study promotes the use of the ISqT as a reliable test among youth soccer players.
321 Interestingly, while both PDet and SDet protocols may be confidently used by practitioners in
322 applied environment, the SDet protocol may be preferred compared to the PDet protocol due
323 to a more advantageous time and logistics efficiency.

324

325 **CONCLUSIONS**

326 The current research highlights the ISqT demonstrates high levels of reliability when conducted
327 with youth soccer players depending on the metric analysed. Practitioners may be confident
328 that reliable ISqT outputs can be obtained only after two familiarisation sessions in applied
329 youth environments. A novel and easy-to-administer SDet protocol led to similar force-time
330 outputs compared to a more traditional PDet protocol. Therefore, it may be considered as an
331 elective and more advantageous alternative for use when working with youth soccer players.

332

333 **ACKNOWLEDGEMENTS**

334 The authors would like to gratefully thank the staff, players and parents of players at Celtic
335 Football Club's academy included in the current research. In addition, thank you to the
336 Academy Head of Sport Science who provided priceless support throughout the data collection
337 process.

338

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445 **FIGURES AND TABLES**

446 **Table 1:** Descriptive data and familiarisation effect on participants' body configuration and
447 force at contraction onset. Data presented are mean \pm standard deviation.

448 **Table 2:** Percentage change and effect sizes of isometric squat test data between testing
449 sessions for both protocols.

450 **Table 3:** Descriptive data and familiarisation effect on force-time metrics. Data presented are
451 mean \pm standard deviation (95% CI lower bound, 95% CI upper bound).

452 **Table 4:** Isometric squat inter-day reliability statistics calculated from data from all 3 testing
453 days.

454 **Figure 1:** Study overview for each protocol. Participants then repeated the same process for
455 the other protocol in a randomised fashion.

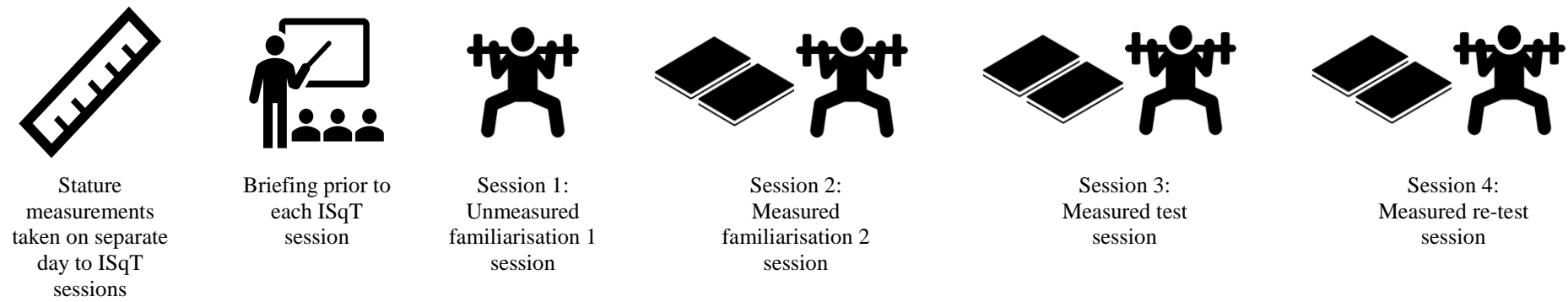


Figure 1: Study overview for each protocol. Participants then repeated the same process for the other protocol in a randomised fashion.

Table 1: Descriptive data and familiarisation effect on participants' body configuration and force at contraction onset. Data presented are mean \pm standard deviation.

Metric	Pre-determined protocol			Self-determined protocol		
	Familiarisation 2	Test	Retest	Familiarisation 2	Test	Retest
Stance Width (cm)	43.1 \pm 5.4	43.6 \pm 5.3	42.3 \pm 4.8	38.5 \pm 5.4	39 \pm 5.3	39.2 \pm 4 ^{\$}
Bar height (cm)	126.6 \pm 10.3	127.3 \pm 10	127 \pm 10.4	134.4 \pm 8.9	132.7 \pm 10	134 \pm 9.2 ^{\$}
Knee joint angle (°)	124.7 \pm 3.3	125 \pm 3.6	125 \pm 3.1	136.5 \pm 6.7	135 \pm 8.1	135.3 \pm 7.6
Force at contraction onset (N)	656 \pm 103	679 \pm 124	669 \pm 109	677 \pm 124	656 \pm 109	674 \pm 123 ^{\$}

Key: N: newton; cm: centimetres; °: degrees; ^{\$}: protocol average of 3 trials significantly different to that of pre-determined protocol.

Table 2: Percentage change and effect sizes of ISqT data between testing sessions for both protocols.

Metric	Pre-determined protocol				Self-determined protocol			
	Familiarisation 2-Test		Test-Retest		Familiarisation 2-Test		Test-Retest	
	Δ (%)	Hedges g	Δ (%)	Hedges g	Δ (%)	Hedges g	Δ (%)	Hedges g
Stance Width (cm)	1.2	-0.10	-3.0	0.25	1.3	-0.10	0.5	-0.04
Bar height (cm)	0.5	-0.06	-0.2	0.03	-1.2	0.17	1.2	-0.17
Knee joint angle (°)	0.3	-0.11	-0.1	0.02	-1.1	0.20	0.3	-0.04
Force at contraction onset (N)	3.4	-0.20	-1.4	0.08	-3.1	0.17	2.6	-0.15
Peak Force (N)	6.1	-0.25	0.2	-0.01	1.4	-0.06	1.5	-0.07
rPF (N/kg)	5.1	-0.39	1.5	-0.12	2.8	-0.18	0.0	0.00
IMP50 (Ns)	3.8	-0.21	-3.4	0.18	-3.9	0.20	2.5	-0.13
IMP100 (Ns)	3.0	-0.16	-2.7	0.15	-4.1	0.22	3.4	-0.19
IMP150 (Ns)	1.9	-0.10	-1.2	0.06	-3.3	0.16	2.7	-0.14
IMP250 (Ns)	2.4	-0.12	-1.4	0.07	-2.6	0.12	2.1	-0.11
RFD50 (N/s)	-2.5	0.04	4.8	-0.07	2.7	-0.05	-7.4	0.13
RFD100 (N/s)	-1.8	0.03	4.4	-0.08	-4.2	0.08	-0.5	0.01
RFD150 (N/s)	2.6	-0.06	-1.6	0.03	-0.3	0.01	-4.2	0.10
RFD250 (N/s)	5.2	-0.14	-1.9	0.05	1.1	-0.03	-2.2	0.06

Key: Δ : percentage change between testing sessions; rPF: relative peak force; IMP50: impulse from 0-50ms; IMP100: impulse from 0-100ms; IMP150: impulse from 0-150ms; IMP200: impulse from 0-200ms; RFD50: rate of force development from 0-50ms; RFD100: rate of force development from 0-100ms; RFD150: rate of force development from 0-150ms; RFD200: rate of force development from 0-200ms; N: newton; N/kg: newton per kilogram of body mass; Ns: newton-seconds; N/s: newtons per second.

Table 3: Descriptive data and familiarisation effect on force-time metrics. Data presented are mean \pm standard deviation (95% CI lower bound, 95% CI upper bound).

Metric	Pre-determined protocol			Self-determined protocol		
	Familiarisation 2	Test	Retest	Familiarisation 2	Test	Retest
Peak Force (N)	2009 \pm 501 (-1314, 2703)	2138 \pm 505 (-1439, 2837)*	2143 \pm 519 (-1424, 2862)*	2145 \pm 497 (-1456, 2834)\$	2176 \pm 460 (-1538.70, 2813.082)\$*	2209 \pm 528 (-1478, 2940)\$*
rPF (N/kg)	37.50 \pm 5.20 (-30.33, 44.66)	39.50 \pm 5.00 (-32.59, 46.39)*	40.10 \pm 5.20 (-32.97, 47.26)*	39.73 \pm 6.10 (-31.28, 48.19)	40.89 \pm 6.53 (-31.84, 49.94)*	40.87 \pm 6.07 (-32.46, 49.28)*
IMP50 (Ns)	35.78 \pm 5.99 (-27.47, 44.08)	37.19 \pm 6.99 (-27.50, 46.87)	34.6 \pm 9.08 (-22.01, 47.18)	36.91 \pm 6.96 (-27.26, 46.55)	35.52 \pm 6.49 (-26.53, 44.52)	36.44 \pm 7.14 (-26.55, 46.33)
IMP100 (Ns)	78.37 \pm 14.55 (-58.21, 98.54)	80.78 \pm 14.18 (-61.13, 100.42)	78.65 \pm 13.93 (-59.34, 97.96)	82.03 \pm 15.20 (-60.98, 103.09)	78.8 \pm 14.44 (-58.78, 98.82)	81.6 \pm 14.96 (-60.87, 102.34)
IMP150 (Ns)	131.01 \pm 27.76 (-92.54, 169.48)	133.6 \pm 25.19 (-98.69, 168.51)	132.02 \pm 26.74 (-94.97, 169.076)	138.43 \pm 28.77 (-98.55, 178.30)	133.94 \pm 25.88 (-98.07, 169.82)	137.6 \pm 26.41 (-101, 174.2)
IMP250 (Ns)	190.93 \pm 42.02 (-132.69, 249.17)	188.9 \pm 52.3 (-116.39, 261.40)	178.69 \pm 65.25 (-88.26, 269.11)	202.92 \pm 45.17 (-140.31, 265.52)	197.81 \pm 39.29 (-143.36, 252.26)	202.10 \pm 41.23 (-144.96, 259.24)
RFD50 (N/s)	1555.6 \pm 920.1 (-280.43, 2830.77)	1465.38 \pm 1080.07 (31.49, 2962.25)	1476.37 \pm 1147.69 (114.21, 3066.95)	1739.48 \pm 969.42 (-395.96, 3083.00)	1787.29 \pm 915.04 (-519.13, 3055.44)	1664.77 \pm 964.95 (-327.44, 3002.10)
RFD100 (N/s)	2997.17 \pm 1803.62 (-497.53, 5496.81)	2842.79 \pm 1641.66 (-567.61, 5117.98)	2850.85 \pm 1973.94 (-115.15, 5586.55)	3589.55 \pm 2087.96 (-708.31, 6470.79)	3444.14 \pm 1538.86 (-1311.43, 5576.85)	3427.08 \pm 1775.51 (-966.39, 5887.76)
RFD150 (N/s)	3199.93 \pm 1620.97 (-953.43, 5446.44)	3173.69 \pm 1544.11 (-1033.7, 5313.68)	2995.81 \pm 1741.63 (-582.08, 5409.55)	3645.55 \pm 1752.97 (-1216.12, 6075)	3634.29 \pm 1370.75 (-1734.56, 5534.01)	3486.50 \pm 1624.82 (-1234.65, 5738.35)
RFD250 (N/s)	3015.7 \pm 1213.79 (-1333.50, 4697.9)	3072.17 \pm 1285.61 (-1290.44, 4853.90)	2890.37 \pm 1440.2 (-894.39, 4886.36)	3438.03 \pm 1434.27 (-1450.27, 5425.8)	3477.89 \pm 1099.52 (-1954.06, 5001.72)	3403.15 \pm 1377.49 (-1494.08, 5312.22)

Note: ICC: intraclass correlation coefficient; CI: confidence interval; CV: coefficient of variation; rPF: relative peak force; IMP50: impulse from 0-50ms; IMP100: impulse from 0-100ms; IMP150: impulse from 0-150ms; IMP200: impulse from 0-200ms; RFD50: rate of force development from 0-50ms; RFD100: rate of force development from 0-100ms; RFD150: rate of force development from 0-150ms; RFD200: rate of force development from 0-200ms; N: newton; N/kg: newton per kilogram of body mass; Ns: newton-seconds ; N/s: newtons per second; \$: significantly different to pre-determined protocol; *: significantly different to familiarisation session 2; †: significantly different to test session; ‡: significantly different to retest session.

Table 4: Isometric squat inter-day reliability statistics calculated from data from all 3 testing days.

Metric	Pre-determined protocol		Self-determined protocol	
	ICC (95%CI)	CV (%) (95%CI)	ICC (95%CI)	CV (%) (95%CI)
Stance Width (cm)			0.55 (0.30-0.75)	9.6 (7.5-13.3)
Bar height (cm)			0.87 (0.76-0.93)	2.9 (2.3-4)
Knee joint angle (°)			0.50 (0.23-0.71)	4.1 (3.2-5.6)
Force at contraction onset (N)			0.90 (0.81-0.95)	5.3 (4.2-7.3)
Peak Force (N)	0.92 (0.83-0.97)	8.4 (6.7-11.6)	0.88 (0.74-0.95)	7.7 (6.0-10.5)
rPF (N/kg)	0.70 (0.45-0.86)	8.0 (6.3-11.0)	0.83 (0.65-0.93)	6.9 (5.4-9.4)
IMP50 (Ns)	0.78 (0.57-0.90)	9.1 (7.1-12.5)	0.82 (0.63-0.92)	8.6 (6.8-11.8)
IMP100 (Ns)	0.85 (0.70-0.94)	7.6 (6.0-10.4)	0.77 (0.55-0.90)	9.4 (7.4-12.9)
IMP150 (Ns)	0.89 (0.78-0.96)	7.2 (5.7-9.9)	0.75 (0.52-0.89)	10.5 (8.2-14.4)
IMP250 (Ns)	0.90 (0.79-0.96)	7.6 (6.0-10.5)	0.75 (0.53-0.89)	10.8 (8.5-14.9)
RFD50 (N/s)	0.45 (0.12-0.72)	62.2 (46.9-92.5)	0.37 (0.04-0.67)	61.3 (46.2-91.0)
RFD100 (N/s)	0.81 (0.62-0.92)	31.5 (24.3-44.8)	0.47 (0.14-0.74)	53.7 (40.7-79.0)
RFD150 (N/s)	0.81 (0.63-0.92)	28.4 (22.0-40.4)	0.60 (0.31-0.81)	35.4 (27.2-50.7)
RFD250 (N/s)	0.85 (0.68-0.93)	22.7 (17.6-31.9)	0.74 (0.51-0.88)	23.2 (18.1-32.7)

Key: ICC: intraclass correlation coefficient; CV: coefficient of variation; rPF: relative peak force; IMP50: impulse from 0-50ms; IMP100: impulse from 0-100ms; IMP150: impulse from 0-150ms; IMP200: impulse from 0-200ms; RFD50: rate of force development from 0-50ms; RFD100: rate of force development from 0-100ms; RFD150: rate

of force development from 0-150ms; RFD200: rate of force development from 0-200ms; N: newton; N/kg: newton per kilogram of body mass; Ns: newton-seconds ; N/s: newtons per second.