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

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Abstract

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

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

INTRODUCTION

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

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

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

METHODS

SUBJECTS

A priori power analysis using G*Power (Universität Düsseldorf, Düsseldorf, Germany) determined that a minimum of 17 participants would be required to detect a large correlation of $r = 0.7$ among repeated measures with 80% power and an alpha of 5% for a correlational design study. However, this sample size was superseded by the requirement of 28 participants for the repeated measures design used to investigate familiarization effects and compare the mechanical outputs between the PDet and a SDet protocol. A conservative correlation of 0.7 was chosen following pilot testing, where a minimum correlation coefficient equal to $r = 0.9$ was observed for peak force (PF) values. Therefore, 31 well-trained male youth soccer players (mean ± SD: age: 13.2 ± 1.0 years; body mass: 54.1 ± 3.4 kg; stature: 166.3 ± 11.2 cm; percentage of estimated adult height (%EAH): 92.6 ± 3.6%) participated in this study. %EAH was determined using equations specific to European males chronological age based off mid-parent height [9], which was adjusted for overestimation [10]. Participants self-reported an average of 2.0 ± 0.9 years of strength, weight or gym training, including 6 months of supervised training which did not include back squat technique training. This investigation was conducted in accordance with the Declaration of Helsinki and approved by an institutional Ethics Board prior to data collection.

DESIGN

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

FIGURE 1 ABOUT HERE

METHODOLOGY

Testing sessions were completed across a period of 1-11 days. Prior to each testing session, a warm-up consisting of dynamic squatting, mobility, glute bridging, and lunging activities followed by three warm-up isometric squats at 60%, 70% and 80% [5] of maximum perceived effort was performed. Thereafter, the protocol was explained and coaching cues provided for correct execution to ensure consistency of technique. The ISqT efforts were performed using an isometric rack with adjustable bar height to the nearest 7 cm. Dual-force plates (VALD Performance, ForceDecks, Queensland, Australia) were positioned below the bar within the isometric rack and recorded ground reaction force (GRF) data at 1000Hz [11]. Force plates were zeroed before each isometric effort and body mass recorded whilst standing still prior to the first isometric effort of each session.

Participants gripped the bar with equal spacing of hands from its centre while standing off the force plates. Participants then stepped onto the force plates and assumed a squat position with the bar placed above the posterior deltoids and ensured to maintain a neutral pelvis and spinal alignment during each effort to mitigate injury risk and allow for effective transfer of force. Participants then lightly pressed their shoulders against the bar ready to push as well as to remove slack from the bar and minimise early compliance due to skeletal muscle compression during the effort [12].

Participants held this position to obtain a steady weighing period for 1-3 seconds [2] prior to each isometric effort, which was ensured by the researcher through inspection of the live force-time trace. This method was chosen upon pilot sessions to obtain an accurate representation of force applied while participants were ready to initiate the isometric effort to ensure no impact upon time dependent metrics. Participants were instructed to "reset" if exerting variable force during the weighing period.

Participants were instructed to push against the ground as hard and as fast as they could [13] following the auditory cue "GO" [5], as pilot data indicated this method obtained smoother rates of force development following contraction onset compared to self-selected onsets (unpublished data). Trials were stopped and discarded if a large (>50N) countermovement was detected during the weighing period, or if pain was reported, or movement occurred. Encouragement was provided during each effort and the child's pose stretch was carried out post-effort to alleviate any acute posterior lumbo-pelvic muscle tension. Feedback was provided in "real-time" via a TV screen stationed in front of a customised rack (IndigoFitness, Nuneaton, England) to ensure maximal effort [14,15]. Participants were informed of their PF output following each effort to promote motivation to perform [15,16]. Kinetic performance was assessed by the researcher [12] with feedback provided before and after each effort [14,17,18].

PRE-DETERMINED ISOMETRIC SQUAT PROCEDURES

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

SELF-DETERMINED ISOMETRIC SQUAT PROCEDURES

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

ISOMETRIC SQUAT FORCE-TIME DATA ASSESSMENT

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

SELF-REPORT MEASURES

Perception of autonomy was evaluated using a modified Basic Psychological Needs in Exercise Scale upon completion of each protocol [22]. A modified version was utilised due to the potentially confusing wording of questions in this questionnaire for immature adolescent populations. Participants rated four questions using a Likert scale, ranging from 1 (“Strongly Disagree”) to 5 (“Strongly Agree”). The questions were: “1. The testing programme I just participated in is the same as how I would like to train/ be tested in the future”, “2. The way I was just tested is the way I want to be tested in the future”, “3. I feel I am able to decide how I am tested in the future”, and “4. Making choices about the exercise/activities I do is important to me”. This final question was added in order to assertain participants’ feelings on the importance of autonomy over testing procedures.

STATISTICAL ANALYSIS

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

Hedges *g* effect sizes [23] were calculated to determine the magnitude of the differences in values between trials for both protocols and interpreted as described previously [24]. In addition, percentage changes between testing sessions was also calculated for all force-time and body configuration metrics.

Intraclass correlation coefficients (ICC) and coefficient of variation (CV) and associated 95% confidence intervals (CI) were calculated to test inter-day reliability. An ICC lower than 0.5, between 0.5 and 0.75, between 0.75 and 0.9, and greater than 0.90 was interpreted as poor, moderate, good, and excellent relative reliability, respectively [25]. A CV ≤10% was deemed as acceptable absolute reliability [26]. Reliability analysis was performed using customised spreadsheets [27].

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

$$\mathrm{Y_i} = \beta_0 + \beta_{1\text{-}3\,session\ number} + \beta_{4protocol} + \varepsilon_{\mathrm{i}}$$

The measured dependant variable (Y) for each observation (${}_i$; participant) represents repeated measures for each subject, β_0 is the overall grand intercept and ε_{i} is the residual error (i.e., unexplained variance) or the model. Predictor variables included: measurement session ($\beta_{1\text{-}3}$; categorical variable with 3 levels [familiarisation session 2; test session, re-test session]) and protocol (β_4; categorical variable with 2 levels [PDet; SDet]). Moreover, random effects were assumed for participants, training structures and exercise, with random slopes introduced in the model if their addition did not result in a convergence error. Estimated marginal means and 95% confidence intervals were calculated alongside comparisons made using post-hoc Holm-Bonferroni adjustments. Visual inspection of residual plots was used to confirm the assumptions of homoscedasticity or normality, which was also assessed through the Shapiro-Wilk test. Analysis was performed in R language and environment for statistical computing using the lme4, lmerTest, emmeans, and ggeffects packages while model assumptions were checked using the performance package (4.0.5; R Core Team, Vienna, Austria).

RESULTS

PROTOCOL COMPARISONS

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

TABLE 1 ABOUT HERE

TABLE 2 ABOUT HERE

TABLE 3 ABOUT HERE

RELIABILITY

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

TABLE 4 ABOUT HERE

EFFECTS OF FAMILIARIZATION

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

SELF-REPORTED PERCEPTIONS OF AUTONOMY

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

DISCUSSION

The primary aim of this study was to establish the between-day reliability of force-time metrics measured in the ISqT among adolescent soccer players. The secondary aim was to determine the number of sessions required for data to stabilise. Finally, this investigation aimed to compare PDet and SDet outputs. Average values obtained from ISqT displayed acceptable reliability statistics among youth soccer players, however, the 95% CI often exceeded the aforementioned reliability threshold (ICC $\geq$0.75 and CV $\leq$10%). PF, rPF and IMP for any time epoch demonstrated acceptable average reliability values for both protocols, whereas RFD was deemed unacceptable regardless of the timeframe analysed (Table 4). PF outputs produced during the SDet protocol were significantly larger compared to the PDet protocol, with no other differences for any other mechanical measure between protocols (Table 3). Two familiarisation sessions consisting of three trials are sufficient to when utilising an ISqT with youth athletes, regardless of the protocol employed (Table 3).

In agreement with previous literature, PF displayed excellent [12,19,28] and good [5] average relative reliability for the PDet and SDet protocols, respectively (Table 4). In addition, average rPF also displayed good reliability for the SDet protocol, but moderate reliability for the PDet protocol (Table 4). Drake *et al.* [29] reported excellent between-day test reliability for rPF (ICC: 0.92 and CV: 5%) when utilising a PDet body position in the ISqT. This maybe as a result of a change in the participants rank order as highlighted by the large 95% CIs of the ICC compared to that of the CV (Table 4). Indeed, differing rates of isometric data stabilisation in youth compared to adults may contribute to such a result [30]. Therefore, the rPF metric may be slightly less reliable when measured in youth compared to adult participants.

In agreement with previous research [19,31] acceptable reliability (ICC $\geq$0.75 and CV $\leq$10%) was observed for IMP across all time epochs regardless of protocol (Table 4). However, RFD metrics were mostly unreliable regardless of time epoch or protocol (Table 4). Drake, Kennedy and Wallace [29] found unreliable RFD reliability statistics irrespective of the time epoch (up to 0-250ms) analysed. Similarly, research reporting CVs across multiple time epochs highlighted variability of 19.9-89.1% in adult participants [29] and unacceptable (CV: 16.8%) statistics for the IMTP in adolescent athletes [8]. Therefore, RFD obtained from multi-joint isometric tests is likely an unreliable metric to use with youth.

ISqT force-time outputs stabilized after two sessions consisting of three trials each (Table 3). This is in contrast to Drake, Kennedy and Wallace [5], who reported stable PDet ISqT force-time characteristics after three familiarisation sessions. A potential reason explaining this finding were the different participants' characteristics. While the current study involved youth soccer players with a strength training experience of 2.0 ± 0.9 years, Drake Kennedy and Wallace [5] investigated strength trained (training experience: 4.1 ± 1.8 years) adult males (age: 21.4 ± 4.5 years). Additionally, where the current investigation utilised the maximum PF value, Drake Kennedy and Wallace [5] used the average between trials, confounding comparisons between studies. PF was found as stable over four weeks when testing IMTP in youth soccer players [32].

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

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

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

The current study is not without limitations. Participants in the current study are youth male soccer players, which limits generalization to other cohorts. However, the PF outputs of the current study were similar to those displayed by youth athletes from various sports [33]. In addition, generalisation to other isometric tests is not possible due to differences in body configuration between tests. In addition, previous research has found reliable time-dependent force-time metrics (e.g., RFD) through the use of ‘explosive’ 1 second protocols [12,29], therefore it maybe that the protocol duration of the current study was not conducive to eliciting reliable RFD outputs. However, the aforementioned protocol [12,29] remains to be evaluated in youth. In addition, due to the time commitment needed to carry out additional 1-second explosive protocols with the requisite recovery period, this was not feasible in the current investigation.

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

PRACTICAL APPLICATIONS

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

CONCLUSIONS

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

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FIGURES AND TABLES

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

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

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

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

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

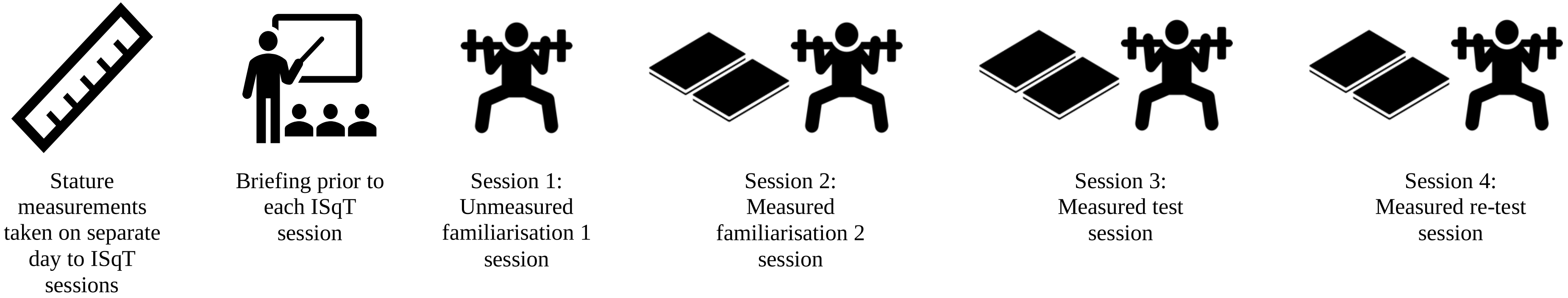

Figure 1: Study overview for each protocol. Participants then repeated the same process for the other protocol in a randomised fashion.

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

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

	Pre-determined protocol				Self-determined protocol			
	Familiarisation 2-Test		Test-Retest		Familiarisation 2-Test		Test-Retest	
Metric	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 ± standard deviation (95% CI lower bound, 95% CI upper bound).

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

	Pre-determined protocol		Self-determined protocol	
Metric	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.