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Intra-Trial Reliability and Usefulness of Isometric Mid-Thigh Pull Testing on Portable Force Plates

by
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The aim of this study was to assess the intra-trial reliability and usefulness of portable force plates and a customised Isometric Mid-Thigh Pull rig. Twenty males (age: 24.1 ± 2.5 years, body height: 177.7 ± 0.09 cm, body mass: 88.4 ±17.9 kg) with weightlifting experience ±12 months attended 1 familiarisation session and 1 testing session where 4 isometric mid-thigh pulls were performed. Maximum force, absolute peak force (PF), relative PF, allometrically scaled PF, and force (150, 200, 250 ms) were deemed reliable (ICC ≥ 0.91 and CV ≤ 9.8%) based on predetermined criteria (ICC ≥ 0.8 and CV ≤ 10%). The impulse and the rate of force development (RFD) were deemed unreliable (ICC ≤ 0.91 and CV ≥ 10 %) at all time points. Maximum force, absolute PF, relative PF to body weight and body mass, rand allometrically scaled PF, had a typical error (TE) lower than the smallest worthwhile change small effect (SWC0.2) and moderate effect (SWC0.5) and were rated as good with regard to usefulness. The TE for force at selected time points (150, 200, 250 ms) was also higher than the SWC0.2, achieving a rating of marginal, but TE was higher than SWC0.5, achieving a rating of good with regard to usefulness. Portable force plates and customised rigs can reliably determine peak force and force output at different time points and for detecting the SWC in maximum and absolute force measures, greater familiarisation may be required to establish reliability of other variables such as the impulse and the RFD.

Key words: isometric strength, force time curve, mid-thigh pull, performance testing.

Introduction

The ability to generate maximum force and apply force rapidly is deemed important for various sports performance, especially in actions where high forces are required to be applied rapidly such as throwing, jumping and striking, or where high power is required to accelerate or change direction (Newton and Kraemer, 1994). There are numerous methods that can be used to establish the force and velocity characteristics of athletes with a view to identifying aspects of the force time curve which can direct the focus of subsequent training (McGuigan et al., 2006; Morin and Samonzino, 2016). Methods such as the eccentric utilization ratio, vertical ballistic push off performance in jumping and force and velocity profiles in sprinting have been used in previous research (Mcguigan et al., 2006; Morin and Samonzino, 2016). The Isometric Mid-Thigh Pull (IMTP) is a popular method of establishing maximum force and explosive strength related capabilities of athletes (Haff et al., 1997). It is considered a safe and time efficient alternative to traditional 1 repetition maximum testing as less technical competency is required to carry out a maximum effort and multiple sets are not required (Dos Santos et al., 2016). Typically, the IMTP requires the athlete to adopt a knee angle of approximately 130 - 140° with the trunk in an upright position (Haff et al., 1997). The IMTP allows for the collection of specific force time variables such as peak force (PF), force at selected time points, impulse and rate of force development (RFD). IMTP force variables have been reported to correlate with specific movements in numerous sports including

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weightlifting, where absolute peak force (maximum force minus body weight) variables were correlated very strongly with absolute values for competition performance (Beckham et al., 2013), sprint performance in soccer where a moderate correlation was reported between force at 100 ms and sprint time (Kuki et al., 2017), and in collegiate athlete's where moderate to strong correlations were found between sprint speed and change of direction, and PF, impulse, and rate of force development (Thomas et al., 2015a). Traditionally isometric tests such as the IMTP are performed in laboratories using embedded force plates and commercially manufactured apparatus, and such permanent settings are regarded as the gold standard of isometric testing (Lake et al., 2018). Recently, dual portable force plates, which are easily transportable, have come on the market at a significantly lower cost than embedded plates and portable single force platforms (Lake et al., 2018). The availability of these plates has increased the popularity of isometric tests in customised apparatus. While these low-cost solutions enable practitioners to assess a variety of time force variables such as RFD, impulse and force at selected time points, quickly and easily, there is limited information on the reliability and usefulness of these plates when used in conjunction with customised testing equipment. Seeking to monitor changes in variables such as the rate of force development, customised equipment may contribute to excessive noise during recording which will lessen the quality of the data recorded. While these portable plates are considerably more economical and therefore offer greater accessibility than previous products, if the force time variables collected using them are going to inform the design of training interventions, it is imperative that the data being recorded are valid and reliable. Valid and reliable data are crucial not only to give direction to training, but also in the monitoring and assessment of the effectiveness of training interventions. Previous research has investigated the test re-test reliability and criterion validity of force-time curve variables collected through a portable isometric mid-thigh clean pull device performed on a single axial load cell (James et al., 2017). While peak force was reported as highly reliable with a conventional force platform (ICC 0.88, CV 9.2% and ICC 0.96, CV 3.10%

respectively), the rate of force development and force at selected time points did not reach acceptable levels of reliability compared to the force platform (ICC ≤ 0.31, CV ≥ 17.3% and ICC ≤ 0.31, CV ≥ 16.2%, respectively) (James et al., 2017). Similarly, research using a custom built IMTP dynamometer against a criterion measure (i.e., 1,000-Hz force platform) for assessing muscle strength in male youth rugby league athletes (Till et al., 2018) reported underestimated peak force and peak force/body mass obtained using a criterion force platform, but with strong correlations between the dynamometer and the force platform. While single load cells and dynamometers can be used to quantify peak forces, other variables such as force, impulse and rate of force development, require force plates to offer more in-depth analysis of physical qualities at the recommended sampling frequency of 1000 Hz (Bartlett, 2007).

The plates used in the current study (PASPORT force plate, PS-2141, PASCO Scientific, California, USA) have reported validity and good reliability in vertical jump force time characteristics (Lake et al., 2018), but to the authors knowledge no study has utilised these plates to analyse the force time curve in the IMTP in conjunction with a customised rig. James et al. (2017) used a heavy-duty ratchet strap attached to the load cell, and the other end attached to a traditional lat-pulldown bar made of solid steel, 25 mm in width with knurled grips and a revolving swivel hanger, the current study used a box steel constructed rig with a 25 mm cold pressed steel bar supported in two support arms rendering the bar immovable (Figure 1).

To examine the test reliability, it is proposed that both the intraclass correlation coefficient (ICC) and the typical error expressed as a coefficient of variation (CV) should be calculated along with 95% confidence intervals (CIs) (Hopkins, 2000). Previous research has suggested using both the threshold of an ICC ≥ 0.80 and a CV ≤ 10% when assessing isometric contractions (Brady et al., 2017).

Once a performance test is deemed reliable, the smallest worthwhile change (SWC) should be calculated (Brady et al., 2017). The use of Typical error (TE) in conjunction with the SWC is recommended to enable practitioners to make a calculated decision on whether the change in a

test is of practical significance (>SWC) and real (greater than the noise of the test, > TE) (Hopkins, 2004). To the authors knowledge, no previous research has investigated the reliability from an IMTP performed on portable dual force plates. It was hypothesised that the more solid structure used in the current study would reduce any external disruption or noise when the subjects are standing on the force plates, thus increasing the reliability of the force plate data. The sampling rate of the James et al.'s (2017) study was 100 Hz, whereas the current PASCO plates were sampled at 1000 Hz. It is suggested that a minimum sampling frequency of between 500 to 1000 Hz and upwards is used for human motion force plate data collection (Bartlett, 2007). It is recommended that a force plate high sampling frequency is important for providing sufficient resolution with regard to force-time curves (Beckham et al., 2014).

Therefore, the aim of the current study was to determine the intra trial reliability of IMTP force time variables and determine the usefulness of the tests.

Methods

This study assessed the intra trial reliability, typical error, smallest worthwhile change and usefulness of four IMTP trials performed on portable dual force plates in a customised rig. Force time variables of maximum force, PF, RFD, impulse and force were collected and used for reliability and usefulness analysis.

Participants

Twenty recreationally active males (age: 24.1 ± 2.5 years, body height: 177.7 ± 0.09 cm, body mass: 88.4 ± 17.9 kg) with a weightlifting experience of ≥ one year of supervised Olympic lifting in a collegiate weightlifting club, participated in this study. All participants were informed of benefits and risks of the investigation and provided written informed consent prior to participation and all procedures used in the study were approved by the University Research Ethics Committee.

Design and Procedures

Participants took part in two separate testing sessions a minimum of 48 hours apart and no longer than 7 days between trials. Session one was a familiarisation session, the participant's body height and mass were recorded prior to being set up in the correct IMTP position. All participants were familiar with the Olympic lifts and the second pull position as it occurs in these lifts. Participants then completed a standardised warm up consisting of pulling the IMTP bar for 5 s at a self-directed 50%, 3 s at 70 – 80%, 3 s at 90% of maximal effort with 1-min recovery between warm up efforts. Session two required participants to perform a general warm up which consisted of 3 min of cycling, 10 bodyweight squats, 10 bodyweight walking lunges and 10 glute bridges (Brady et al., 2017). Participants were placed in the second pull position of the power clean (Haff et al., 1997) for the IMTP, which resulted in a mean knee angle of 138 ± 7° and a hip angle of 142 ± 8°. Participants were required to maintain the position throughout the test. A hand-held goniometer was used to measure the knee and hip angles. Then each participant performed the same IMTP specific warm up as used in the familiarisation session. Participants rested for 2 min before completing 4 maximal efforts lasting 5 s. There was a 2-min rest interval between each pull (Dos Santos et al., 2017a). Lifting straps were used to limit the loss of grip during pulls. When in position, participants were instructed to "*pull as hard and as fast as you can, push the ground away, drive your feet into the ground and the bar from the floor*" (Kuki et al., 2017) to ensure maximal force was achieved (Halperin et al., 2015).

Participants were instructed to get ready, provide a minimum of pre-tension to the bar to ensure there was no slack in the participants body prior to the start of the pull (Thomas et al., 2015b) and then were given a countdown of "*3, 2, 1, PULL!*". Verbal encouragement was provided during each trial (Haff et al., 1997). If any trial was above or below 250 N of their best trial, it was deemed not to be a maximal effort and was discarded and an additional repetition was performed (Haff et al., 2015). IMTP testing was performed on a custom-made rig allowing the placement of the bar at 4 cm intervals permitting the desired position for each participant. Dual force plates (0.35 m by 0.35 m each), PASPORT force plate, PS-2141, PASCO Scientific, California, USA) sampling at a rate of 1000 Hz were placed on a .65m X .71 m X .003 m bright mild steel platform at the base of the rig. The base was assessed using a spirit level to ensure a level

testing surface.

Data Analysis

A custom-built spreadsheet was used to determine the force time variables. Participants were instructed to remain still in the mid-thigh pull position for 3 s prior to the initiation of the pull. Following the 5 s pull, participants were instructed to remain still for approximately 2 s, amounting to a 10 s collection period for each trial. The onset threshold for the contraction was defined as the point where the force exceeded 5 SD from baseline (Dos Santos et al., 2017a). Maximum force was reported as the highest force attained during the 5 second pull. Absolute PF was reported as the maximum force minus the participant's body weight. Absolute PF was also reported relative to body mass (N/kg) and body weight (N/N). To assess muscle strength independent of body size, allometrically scaled ($N/kg^{0.67}$) absolute PF was used (Stone et al., 2004). In accordance with previously reported literature, the RFD was calculated ($\Delta Force/\Delta Time$) and applied to specific time bands (0 – 30, 0 – 50, 0 – 90, 0 – 100, 0 – 150, 0 – 200, 0 – 250 and 0 - 300 ms; Brady et al., 2017). As the time bands used in calculating the reliability of the RFD measure can significantly affect the data, the time bands were selected as they have been shown to provide greater reliability compared to the Peak RFD (Brady et al., 2017). The Peak RFD is the highest RFD attained in a specific sampling time band (Brady et al., 2017; Haff et al., 2015). The net impulse for the same time bands used in RFD analysis was calculated using force time integration (described as the area underneath the force-time curve at the selected time bands; Morris et al., 2018). Force at the selected time points (30, 50, 90, 100, 150, 200, 250 and 300 ms) was derived from the force recorded at the set time from the onset of contraction.

Statistical Analysis

A customised spreadsheet was used to analyse the force-time data. Shapiro-Wilk statistic was performed on the data to assess normality of distribution using a Microsoft Excel spreadsheet (Hopkins, 2015). An ICC ≥ 0.8 and a CV ≤ 10% were determined as acceptable reliability (Brady et al., 2017). Typical error (TE) was calculated and the usefulness of the test was determined by comparing the TE to the SWC calculated on a Microsoft Excel spreadsheet (Hopkins, 2015). The

SWC was determined by multiplying the between-subject SD by 0.2 (SWC0.2) (Hopkins, 2004), which is the typical small effect or 0.5 (SWC0.5) (Cohen, 1998), which is an alternate moderate effect. If the TE was below the SWC, the test was rated as "good", if the TE was similar to SWC, it was rated as "ok" and if the TE was higher than the SWC the test was rated as "marginal" (Hopkins, 2004).

Results

Descriptive statistics for participants for the variables that attained a criterion of an ICC ≥ 0.8 and a CV% ≤ 10% along with the TE, SWC0.2 and SWC0.5 are shown in Table 1. Figure 1 shows variables that achieved a criterion of an ICC ≥ 0.8 and a CV% ≤ 10%.

Maximum force, absolute peak force (PF), relative PF N/N, relative PF N/kg and allometrically scaled PF, and force at selected time point s (150, 200, and 250 ms) were deemed reliable (ICC ≥ 0.91 and CV ≤ 9.8%) based on predetermined criteria (ICC ≥ 0.8 and CV ≤ 10%) (Brady et al., 2017). Maximum force, absolute peak force (PF), relative PF N/N, relative PF N/kg and allometrically scaled PF, allometrically scaled PF, had a TE lower than the SWC0.2 and SWC0.5 and were rated as good. The TE for Force at selected time points (150, 200 and 250 ms) was also higher than the SWC0.2, achieving a rating of marginal, but TE was higher than SWC0.5, achieving a rating of good. Descriptive statistics for participants for the variables that failed to attain a criterion of an ICC ≥ 0.8 and a CV ≤ 10% along with the TE, SWC0.2 and SWC0.5 are shown in Table 2. Figure 2 shows the variables that failed to achieve a criterion of an ICC ≥ 0.8 and a CV ≤ 10%. The impulse, the rate of force development at all time bands, and force at 30, 50, 90, 100 and 300 ms were deemed unreliable (ICC ≤ 0.91 and CV ≥ 10%).

Figure 1

PASCO portable dual force plates in the customised IMTP rig.
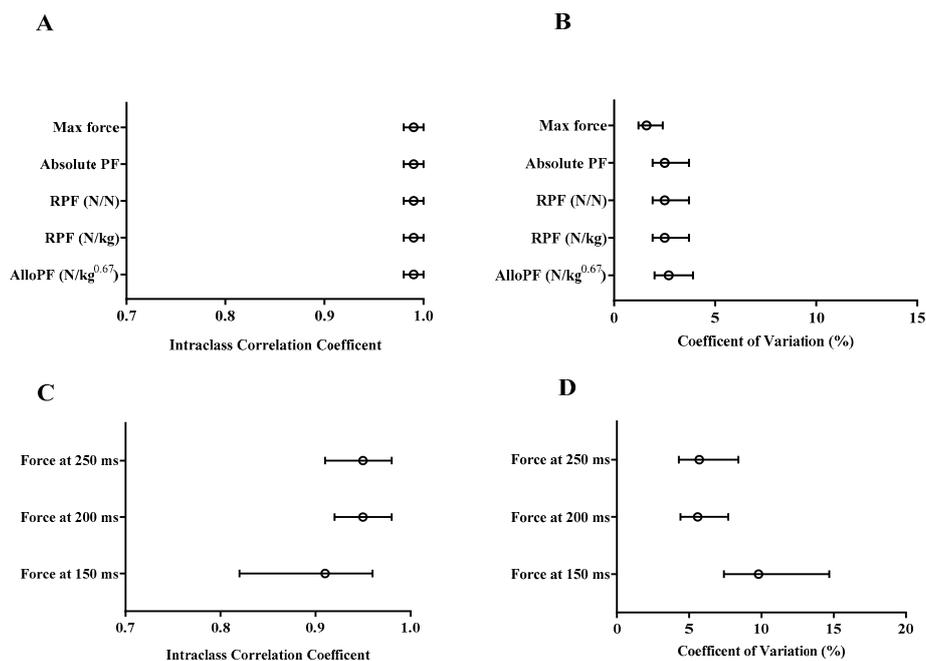
Figure 2

*Reliability measures of the mean ICCs of the variables attaining an ICC > .8
and CV ≤10% in the IMTP. Open circles represent mean ICCs; error bars indicate
95% confidence limits; grey shaded areas represent the zone of acceptable reliability
(ICC > .8, CV < 10%). AlloPF indicates allometrically scaled PF; max force, maximum
force; Absolute PF, absolute peak force; RPF (N/kg), PF relative to body mass;
RPF (N/N), PF relative to body weight. CV, coefficient of variation; ICC, intraclass
correlation coefficient; IMTP, isometric midthigh pull. Force at 150, 200, 250 ms, force
at selected timepoints from the onset of contraction.*
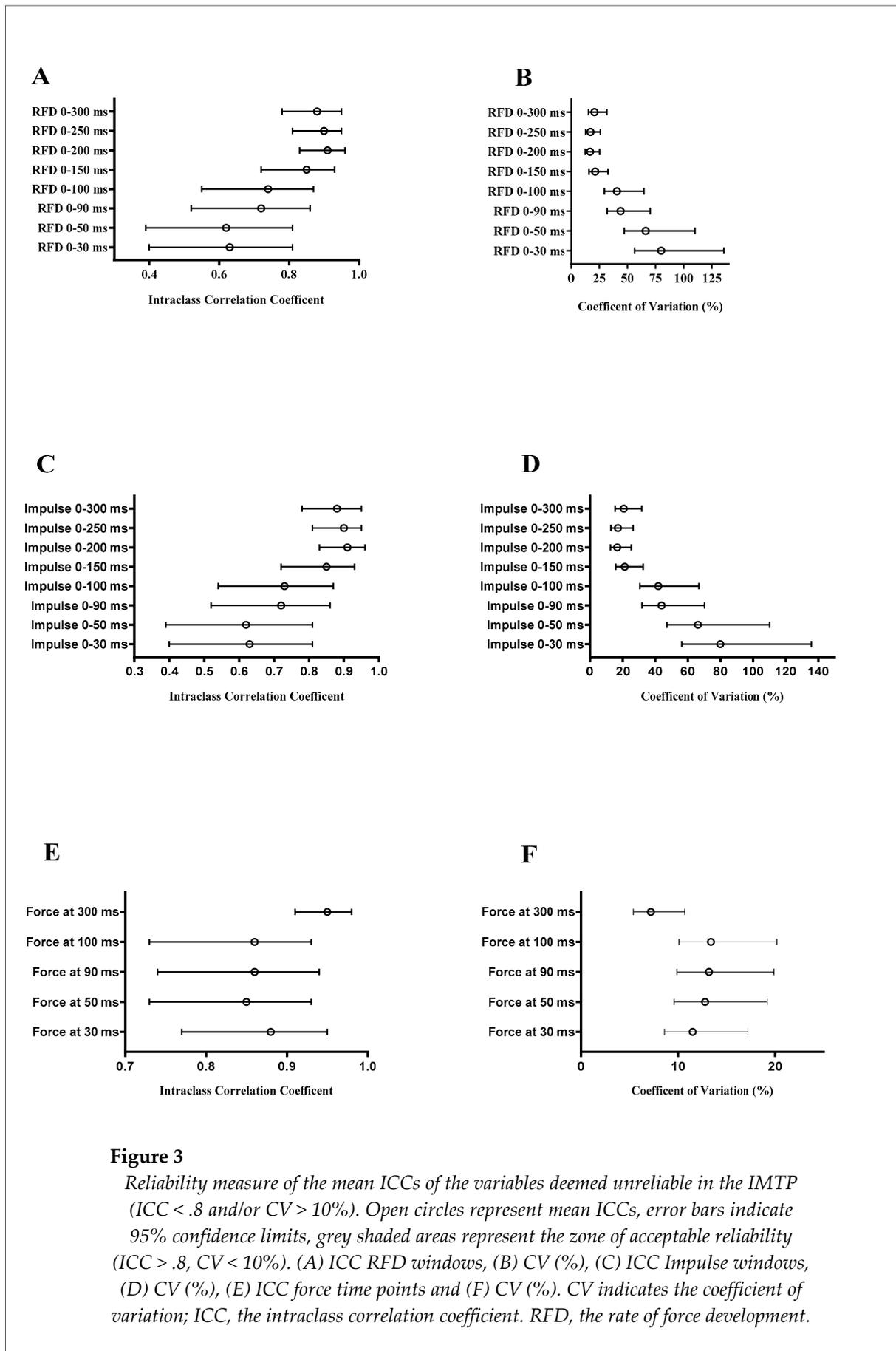
Figure 3
Reliability measure of the mean ICCs of the variables deemed unreliable in the IMTP (ICC < .8 and/or CV > 10%). Open circles represent mean ICCs, error bars indicate 95% confidence limits, grey shaded areas represent the zone of acceptable reliability (ICC > .8, CV < 10%). (A) ICC RFD windows, (B) CV (%), (C) ICC Impulse windows, (D) CV (%), (E) ICC force time points and (F) CV (%). CV indicates the coefficient of variation; ICC, the intraclass correlation coefficient. RFD, the rate of force development.

Table 1

Descriptive statistics of all participants for the IMTP and intra-trial reliability.
Variables attaining a criterion of an ICC > 0.8 and a CV < 10%

Variable	Mean (SD)	ICC	95% CI Lower	95% CI Upper	CV,%	95% CI Lower	95% CI Upper	TE	SWC 0.2	Rating	SWC 0.5	Rating
AlloPF, $N/kg^{0.67}$	13.9 (4.6)	0.99	0.98	1	2.70	2	3.9	0.49	0.9	Good	2.3	Good
RPF, N/kg	21 (6.6)	0.99	0.98	1	2.5	1.9	3.7	0.72	1.3	Good	3.3	Good
RPF, N/N	2.1 (0.7)	0.99	0.98	1	2.5	1.9	3.7	0.07	0.1	Good	0.35	Good
Absolute PF, N	1815.9 (561.1)	0.99	0.98	1	2.5	1.9	3.7	61.61	112.2	Good	281	Good
Max Force, N	2681.8 (646.4)	0.99	0.98	1	1.6	1.2	2.4	60.8	129.3	Good	323.2	Good
Force at 150 ms	1885.3 (561.8)	0.91	0.82	0.96	9.8	7.4	14.7	179.35	112.4	Marginal	280.9	Good
Force at 200 ms	2068.20 (589)	0.95	0.92	0.98	5.6	4.4	7.7	133.85	117.8	Marginal	294.5	Good
Force at 50 ms	2162.2 (584.7)	0.95	0.91	0.98	5.7	4.3	8.4	133.02	116.9	Marginal	292.4	Good
Force at 300 ms	2224.1 (590.5)	0.95	0.91	0.98	7.2	5.4	10.7	134.8	118.1	Marginal	295.3	Good

Abbreviations: AlloPF, allometrically scaled PF; CI, confidence interval;
CV, coefficient of variation; ICC, intraclass correlation coefficient; IMTP, isometric
midthigh pull; PF, peak force; RPF, relative PF; SWC, smallest worthwhile change;
TE, typical error; SD, standard deviation.

Table 2

Descriptive statistics of all participants for the IMTP and intra-trial reliability.
Variables not attaining a criterion of an ICC > 0.8 and a CV < 10%

Variable	Mean (SD)	ICC	95% CI Lower	95% CI Upper	CV,%	95% CI Lower	95% CI Upper	TE	SWC 0.2	Rating	SWC 0.5	Rating
Force at 30 ms	1263 (363)	0.88	0.77	0.95	11.5	8.6	17.2	132	72.6	Marginal	181.5	Good
Force at 50 ms	1364 (388)	0.85	0.73	0.93	12.8	9.6	19.2	155	77.6	Marginal	194	Good
Force at 90 ms	1563 (464)	0.86	0.74	0.94	13.2	9.9	19.9	183	92.8	Marginal	232	Good
Force at 100 ms	1628 (480)	0.86	0.73	0.93	13.4	10.1	20.2	190	96	Marginal	240	Good
Force at 300 ms	2224 (591)	0.95	0.91	0.98	7.2	5.4	10.7	135	118.2	Marginal	295.5	Good
Impulse 0-30 ms	13.9 (10)	0.63	0.4	0.81	79.9	56.3	135.7	6	2	Marginal	5	Good
Impulse 0-50 ms	25.7 (15.3)	0.62	0.39	0.81	66.2	47.2	110.1	9.7	3.06	Marginal	7.65	Good
Impulse 0-90 ms	41.5 (21.9)	0.72	0.52	0.86	43.9	31.9	70.2	12.03	4.38	Marginal	10.95	Good
Impulse 0-100 ms	51.7 (27.3)	0.73	0.54	0.87	41.9	30.5	66.8	14.67	5.46	Marginal	13.65	Good
Impulse 0-150 ms	116.5 (52)	0.85	0.72	0.93	21.3	15.8	32.6	21.28	10.4	Marginal	26	Good
Impulse 0-200 ms	191.9 (73.5)	0.91	0.83	0.96	16.7	12.5	25.3	22.8	14.7	Marginal	36.75	Good
Impulse 0-250 ms	263.4 (93.5)	0.9	0.81	0.95	17.1	12.8	26.4	31.19	18.7	Marginal	46.75	Good
Impulse 0-300 ms	334.7 (116.7)	0.88	0.78	0.95	20.7	15.4	31.7	41.8	23.34	Marginal	58.35	Good
RFD 0-30 ms	1710.5 (1176.2)	0.63	0.4	0.81	79.9	56.3	135.7	739.86	235.24	Marginal	588.1	Marginal
RFD 0-50 ms	2565.3 (1533.2)	0.62	0.39	0.81	66.2	47.2	110.1	969.84	306.64	Marginal	766.6	Marginal
RFD 0-90 ms	5117.7 (2708.3)	0.72	0.52	0.86	43.9	31.9	70.2	1485.36	541.66	Marginal	1354.15	Marginal
RFD 0-100 ms	5187.7 (2714.8)	0.74	0.55	0.87	40.7	29.6	64.6	1447.92	542.96	Marginal	1357.4	Marginal
RFD 0-150 ms	5176.9 (2310.9)	0.85	0.72	0.93	21.3	15.8	32.6	945.84	462.18	Marginal	1155.45	Good
RFD 0-200 ms	4797.4 (1837.3)	0.91	0.83	0.96	16.7	12.5	25.3	560.9	367.46	Marginal	918.65	Good
RFD 0-250 ms	4213.9 (1496.6)	0.9	0.81	0.95	17.1	12.8	26	499.04	299.32	Marginal	748.3	Good
RFD 0-300 ms	3718.4 (1269.9)	0.88	0.78	0.95	207	15.4	31.7	464.46	253.98	Marginal	634.95	Good

Abbreviations: CI, confidence interval; CV, coefficient of variation; ICC, intraclass
correlation coefficient; IMTP, isometric midthigh pull; PF, peak force; RPF, relative
PF; RFD, Rate of Force Development; SWC, smallest worthwhile change; TE, typical error;
SD, standard deviation

Discussion

To the authors knowledge, the current study is the first study to investigate the reliability and usefulness of the IMTP performed on portable dual force plates in a customised portable rig. High intra-trial reliability was reported for maximum force, absolute PF, relative PF (N/N) and (N/kg), allometrically scaled PF, force (at 150, 200 and 250 ms; ICC ≥ 0.8 and CV ≤ 10%). The impulse and the RFD at all time bands were deemed unreliable.

Peak force in the IMTP is the most reliable variable from the force time curve in previous research. In the current study the reliability of PF (ICC 0.99, CV 2.5%) was similar to other studies such as Comfort et al. (2015), (ICC 0.99), Morris et al. (2018), (ICC 0.98, CV 4.91%) and Haff et al. (2015), (ICC = 0.99, CV = 1.7%). Similar reliability for peak force above the selected reliability ranges for this study has been summarised by Brady et al. (2018). Participants in the current study had a mean absolute PF of 1815.9 561.1 N, which is lower than the same variable reported by Brady et al. (2017), (2225 493), Comfort et al. (2015), (2337 603.3) and Dos´Santos et al. (2017b), (2441 647) who used participants from a competitive sporting background. As participants in the current study had only a minimum of 12 month training with the Olympic lift, they could still be regarded as novice and this is reflected in the lower PF values.

The current study utilised portable dual force plates and a customised IMTP rig. James et al. (2017) using a modified IMTP on a single load cell found PF to be reliable, but underestimated compared to the criterion value of a force plate. While portable plates have been shown to provide reliable measures for assessing peak force, the use and application of such information may be limited on its own. Specific values of force production at selected time points will provide more detailed analysis of training interventions and identifying whether the athlete is deficient in either strength or force qualities (Morin and Samonzino, 2016). Beckham et al. (2013) reported that force at 100, 150, 200 and 250 ms also correlated strongly with competition results (r = 0.643 - 0.647, r = 0.605 - 0.636, r = 0.714 - 0.732, r = 0.801 - 0.804) in trained weightlifters.

The current study found force at selected time points was reliable (150, 200, 250 ms), but unreliable at other time points (30, 50, 90, 100 and 300 ms). This finding in the later time points is in agreement with Beckham et al. (2018) who reported reliability for force at 50, 90, 200 and 250 ms in various hip and knee positions (ICC 0.95, CV 8.4%) and Dos'Santos et al. (2017b) who reported within session reliability (ICC = 0.85-0.94, CV = 5.75-10%) and between-session reliability (ICC = 0.86-0.96, CV = 3.76-7.87%) for force (30, 50, 90, 100, 150, 200 and 250 ms). An earlier study by the same authors (Dos'Santos et al., 2016) also reported within session reliability (ICC = 0.80–0.90, CV = 7.3–10.1%) for force values (100,150, and 200 ms). Haff et al. (2015) reported higher reliability (ICC = 0.99, CV = 2.3–2.7%) for specific force values (30, 50, 90, 100, 150, 200, and 250 ms). Kuki et al. (2017) reported that force (100 ms) was unreliable in a group of collegiate soccer players (ICC = 0.71, CV = 36.5%) and proposed that a lack of familiarization may have accounted for these results. In contrast, James et al. (2017) found force to be unreliable at all time points (30, 50, 100, 150, 200 and 250 ms, ICC − 0.26 – 0.1, CV 16.2%), however, this was on a load cell/dynamometer device sampling at 100 Hz.

The current study reported the impulse was unreliable at all selected time bands, this in contrast to much of the previous research which found the impulse to be a reliable variable (Brady et al., 2017; Comfort et al., 2015; Emmond's et al., 2017). Using the same method of calculating the net impulse as in the current study, Morris et al. (2018), noted that reliability for the net and relative impulse over 100 and 300 ms was r = 0.72 (95% CI = 0.59–0.87); CV = 8.8% and r = 0.83 (95% CI = 0.72–0.91); CV = 7.7%.

Emmonds et al. (2017) reported varying degrees of reliability for the impulse in female youth soccer players. The impulse at 100 ms was unreliable for three different age groups (ICC .79), but reliable for one age group (ICC 0.89). The impulse at 300 ms was found to be reliable in three of the age groups (ICC 0.86, CV 9.3%) and unreliable in one age group (ICC 0.73, CV 8.8%). Previous research (Thomas et al., 2015a, 2015b) reported that the impulse at 100, 200 and 300 ms was reliable (ICC ≥ 0.86 and CV ≤ 6.2%). Comfort et al. (2015) also reported within session reliability for the impulse at 100, 200 and 300 ms (ICC > 0.95) in a self-selected IMTP position and in a range of hip and knee angles (ICC = 0.87–.99).

The aforementioned studies that reported reliability for impulse values used participants from an athletic college population, thus it is plausible that the more recreational status of the current study's participants may have contributed to the poor reliability of the impulse. In contrast Brady et al. (2017) reported that the impulse was unreliable at 200 and 250 ms when performed on trained male and female athletes; however, those authors did not present any suggestion for why this time band proved unreliable.

Both Morris et al. (2018) and Emmonds et al. (2017) only used two trials whereas the current study used four trials; it is possible that the additional trials may have contributed to unreliable application of force in the early phases of the pull in a novice cohort. The current study used a 2-min rest interval between pulls as previous studies using the same rest interval have reported reliability with impulse and force (Brady et al., 2017; Thomas et al., 2015a). In contrast to this, other studies finding reliable impulse and force values used rest intervals ranging from 3 to 5 min (Comfort et al., 2015; Emmonds et al., 2017; Morris et al., 2018). The slightly shorter rest interval over 4 consecutive trials in the present study may have contributed to inconsistent force application in the early phase of the pull in relatively inexperienced lifters.

The varying methods of calculating the RFD for analysis in IMTP has been previously highlighted by Brady et al. (2017). The time bands used in calculating the reliability of the RFD measure significantly impacted the results. The RFD at all the assessed time bands was unreliable in the current study, specifically, using selected time bands (e.g., 0–30 ms, 0–50 ms etc.) for the quantification of the RFD results in greater reliability when compared with the quantification of the pRFD. Recently, Moeskops et al. (2018) reported various RFD measures between sessions unreliable at different sampling intervals (50, 90, 150, 200 and 250 ms) with a wide range in the ICC (0.10–0.76) and high CV% (CV% = 31.6–143.1%). James et al. (2017) also found the RFD to be unreliable with CV% ranging from 16.2 to 73.4% and ICC spanning 0.1 to 0.31.

Using the same onset of contraction criteria as the present study, Dos'Santos et al. (2017a), reported reliability of the RFD for 0 – 100, 0 – 150 and 0 – 200 ms (ICC 82, CV 14.3),

however, the CV% used (≤ 15%) was outside the acceptable limits of the current study. Previously, Dos'Santos et al. (2016) reported that RFD time bands (0 – 100, 0 – 150 and 0 – 200 ms) achieved high reliability across a range of sampling frequencies (ICC ≥ .80, CV ≤ 10.1%).

Considering participants in the current study only had a minimum of 12 months of training experience in the Olympic lifts, a lack of reliability in the impulse and the RFD might have been expected. It is possible that a more athletically trained group may be more familiar with the testing positions and in the explosive application of maximum force. As previously stated, the lower PF values recorded in the current study may indicate that the lower strength levels could have impacted on the variability of other force-time variables. Some studies used very young population groups from 7 to 17 years (Emmonds et al., 2017; Moeskops et al., 2018) which may have impacted on the reliability of the data in those studies, as this age group may lack the muscular co-ordination, strength and consistency to apply maximum force in repeated trials. This inconsistency may also be present in recreational participants who underwent just one familiarisation session like in the current study. Beckham et al. (2018) suggest that inexperienced lifters may spend less time overloading the second pull position and this may have contributed to the unreliability in this study. The early RFD is inherently less reliable than other variables (Maffiuletti et al., 2016) and this may have been compounded in the current study by the novice nature of the participants.

The TE was less than the SWC0.2 for maximum force and all absolute PF tests, demonstrating that the portable dual plates are useful in detecting if a "meaningful change" in performance has occurred for these variables. All force, impulse, and RFD variables at all time bands were rated as "marginal" for SWC0.2. The TE was above the SWC0.5 for the RFD at 30, 50, 90, and 100 ms, thus rating the usefulness as "marginal" for these variables. For all other variables analysed, the TE was above the SWC0.5 for each test rating the usefulness as "good". Where the TE is above the SWC0.2, coaches and practitioners can use SWC0.5 to provide the context of "meaningful change" to group analysis since the SWC0.2 may lack the sensitivity (Brady

et al., 2017).

While high reliability was reported for all PF variables, poor reliability was observed in some of the force time measures in the current study, the authors suggest that more familiarisation with the application of maximum force from the onset of the test may be required. Practitioners should ensure that as well as using an onset threshold for the contraction as the point where the force exceeded 5 SD from baseline, the stable baseline force trace prior to the initiation of the pull should not have a peak deviation > 50N from average body weight (Dos'Santos et al., 2017a). Future research should consider tracking the change in reliability data through multiple familiarisation tests and also assessing the reliability with participants who have greater training experience of performing the IMTP. With sensitive measures of the RFD, it is plausible that one familiarisation session in the test position may not have been sufficient. The force plates used in this study are relatively new and there currently is a lack of validity and reliability studies on these plates. Similar plates from the same manufacturer have been referenced in other studies, but their exact model was not stated (Brownlee et al., 2018; Townsend et al., 2019), and none of these studies stated the reliability of force time data from an isometric contraction.

Conclusions

The findings of this study demonstrate that portable dual force plates in conjunction with a customised IMTP rig are reliable for the analysis of maximum force, absolute peak force (PF), relative PF, allometrically scaled PF, and force at specific times (150, 200, 250 and 300 ms), but unreliable for the impulse and the RFD in this particular cohort. Strength and conditioning practitioners may use portable force plates and customised IMTP rigs to confidently assess peak force variables and force variables in the reliable time bands. Peak force can be used to assess changes in maximum strength over time and assess the effectiveness of training interventions. The portable dual force plates are useful in detecting the SWC for maximum and absolute force measures. Force at selected time bands may be used to monitor changes in explosive strength, the effectiveness of training designed to improve dynamic strength and as a marker of neural fatigue. Practitioners should monitor intra-trial reliability regularly as they conduct training testing on portable force plates. Future studies should investigate the effect of additional familiarisation on the impulse, force and RFD. Additional familiarisation with participants may lead to increased reliability of the force time measures.

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