

Title Page:

The reliability, variability, and minimal detectable change of multiplanar isometric trunk strength testing using a fixed digital dynamometer

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1 **Abstract:**

2 **Objective** Trunk strength plays a vital role in athletic performance, rehabilitation, and general
3 health, however, current assessment methods are expensive, non-portable, or unreliable. This
4 study aimed to investigate the within- and between-session reliability, variability, standard
5 error of measurement and minimal detectable change (MDC) of trunk strength in the sagittal
6 (flexion and extension) and frontal planes (left and right lateral flexion) using a fixed digital
7 dynamometer.

8 **Methods** 18 participants (ten men; eight women) attended two sessions separated by seven
9 days. Participants were fitted with a trunk harness which was secured to an immovable base
10 via a digital dynamometer. Three maximal voluntary isometric contractions were completed
11 across four positions (prone, supine, left-side recumbant, and right-side recumbant,
12 respectively) on a glute-hamstring raise machine.

13 **Results** All positions demonstrated *excellent* reliability and low variability within session (ICC:
14 0.95–0.98; CV: 5–7%) and between sessions (ICC: 0.98–0.99; CV: 4–6%), across all
15 positions. The between-session MDC ranged from 8% (prone) to 13% (right-side recumbant),
16 translating to absolute values between 2.9 to 3.2 kg across all positions.

17 **Conclusion** Maximal isometric force testing using a fixed digital dynamometer provides
18 reliable measurements of multiplanar trunk strength, providing a practical method for use in
19 clinical practice.

20 **Key Words**

21 Force, Trunk Flexion, Trunk Extension, Lateral Trunk Flexion

22 **Introduction**

23 Trunk strength has an important role to play in athletic performance (Rodríguez-Perea²⁷),
24 facilitating different movement control strategies (Vleeming et al³³) and transferring forces
25 between the upper and lower limbs (Martin et al¹²; Rodríguez-Perea²⁶). Trunk muscle
26 weakness has been shown to be associated with spinal disorders, such as low back pain and
27 disability (Gabr and Eweda⁴; Reyes-Ferrada²⁴). The point prevalence of low back pain is
28 between 18-65% in elite athletes based on the sport they perform (Trompeter et al³²) and
29 accounts for 21% of all causes of global disability (Hoy et al⁸). Accurately measuring
30 multiplanar trunk muscle strength, therefore, is vital in both performance and clinical settings.
31 Both the intra- and inter-session reliability need to be established prior to implementing a new
32 method of measuring trunk strength. This will inform the practitioner of the repeatability or
33 consistency of a test both within a single testing session and between different testing
34 sessions, allowing practitioners to understand if alterations in strength over time reflect true
35 changes or are due to measurement error (Hopkins⁷).

36 The most common method of assessing the physical qualities of the trunk musculature in
37 clinical practice is through isometric endurance holds. Participants maintain a fixed position
38 against gravity where either the anterior, lateral, or posterior trunk is biased until muscular
39 failure is achieved and the position can no longer be maintained (Reiman et al²¹). Isometric
40 endurance holds are correlated with back pain (McGill et al¹⁴), reliable (intraclass correlation
41 coefficient [ICC] 0.79–0.95), and require minimal equipment (Reiman et al²¹). Furthermore,
42 the importance of isometric trunk endurance ratios was first highlighted by McGill et al¹⁴, who
43 suggested a contributing factor to low back pain is an imbalance between the flexion-extension
44 trunk endurance. They specifically suggested when the trunk extensors have a lower
45 endurance than the trunk flexors, individuals are predisposed to developing back pain.
46 Isometric endurance holds, however, assess the endurance characteristics of the trunk
47 musculature and not the maximal strength characteristics. The physiological mechanisms

48 between muscular endurance and maximal strength are different and the assessment of both
49 qualities may yield valuable insights that direct the focus of any training interventions.

50 Several methods of measuring trunk maximum strength exist, namely isokinetic dynamometry,
51 handheld dynamometry, and manual muscle testing (Althobaiti et al¹), however, these
52 approaches all have considerable limitations (Trajković et al³¹). Manual muscle testing has
53 inconsistent reliability (ICC 0.55–0.93) and low sensitivity, limiting its application in groups
54 such as athletes, where precise scores are needed (Trajković et al³¹). Hand-held
55 dynamometry provides a valid (De Blaiser et al³) and sensitive measure of strength, however,
56 mixed reliability (ICC 0.24–0.93) has been observed when measuring trunk flexion and
57 extension strength (De Blaiser et al³; Moreland et al¹⁷). Isokinetic dynamometry is considered
58 the gold-standard for assessing trunk muscle strength (Reyes-Farrada²³), demonstrating both
59 reliability (ICC 0.87–0.95) and validity ($r > 0.99$) when correlated to cross sectional area of the
60 trunk musculature assessed using MRI and surface EMG muscle activity (Guilhem et al⁵). The
61 feasibility of using isokinetic dynamometry in clinical practice is of limited benefit as the device
62 can cost upwards of £40,000, is time-consuming to operate, and immobile, meaning they are
63 typically only found in research settings (Althobaiti et al¹). Classical models also commonly
64 assess strength in unnatural positions and movements, questioning their specificity to athletic
65 performance (Reyes-Ferrada²³).

66 Fixed digital dynamometry is a relatively novel method of measuring muscle strength, wherein
67 a belt-stabilised dynamometer is used to connect the individual to a fixed object, which they
68 pull against isometrically. It has shown *good* to *excellent* reliability (ICC 0.76–0.91) when
69 assessing strength at the shoulder, knee, and hip (Trajković et al³¹), and is inexpensive (£100–
70 £1000), quick to use, and highly portable (Trajković et al³¹). Fixed digital dynamometry also
71 facilitates multiplanar trunk strength testing (i.e., across flexion, extension, and lateral flexion),
72 which has been overlooked in most trunk strength research. Insufficient multidirectional
73 stability of the spine may lead to increased forces imparted onto the passive structures of the
74 spine, and subsequently, a greater risk of pathology (Vleeming et al³³). To date, however, no

75 study has investigated the use of a fixed digital dynamometer to assess trunk strength in any
76 plane.

77 To facilitate clinical reasoning, rehabilitation, and performance programming, there is a need
78 for a practical, inexpensive, and reliable method of assessing multiplanar trunk strength. The
79 first aim of the study is, therefore, to establish the within- and between-session reliability,
80 variability and minimal detectable change (MDC) of trunk muscle strength in the sagittal and
81 frontal planes using a fixed digital dynamometer. The second aim is to establish a descriptive
82 data set of trunk strength measurements within a population of healthy participants. The final
83 aim is to provide a comparison of strength data across positions.

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97 **Methods**

98 **Study Design**

99 A within-subject test-retest design was adopted to examine the reliability, variability, SEM, and
100 MDC of trunk strength tests. The testing was carried out in the Ballet Healthcare suite at the
101 Royal Opera House, London, United Kingdom in July 2023. All data collection was carried out
102 by the same Chartered Physiotherapist, who had more than ten years' experience working
103 within elite sport. Testing was carried out at the same time of day (± 1 hour) for each
104 participant, within an air-conditioned gymnasium, with temperature set at 21 °C.

105 **Participants**

106 An *a priori* power analysis was conducted, identifying a minimum sample of 18 participants
107 needed to calculate the ICC ($\alpha = 0.05$, $\beta = 0.80$), established on three trials recorded per
108 participant in each testing position, with a minimum acceptable reliability (ρ_0) of ≥ 0.7 and an
109 expected reliability (ρ_1) of ≥ 0.9 (Brady et al²; Walter et al³⁴). A convenience sample of 18
110 healthy participants volunteered to take part in this study. Anthropometric measurements were
111 performed following the guidelines of the International Society for the Advancement in
112 Kinanthropometry (ISAK) (Stewart et al³⁰). Measurements were taken prior to testing with the
113 participants barefoot. Bodyweight (kg) was measured using a SECA scale, (SECA, Hamburg,
114 Germany) with 100 g precision and standing height (cm) was measured using a SECA
115 stadiometer (SECA, Hamburg, Germany) with 0.1 mm precision.

116 Participants were recruited through poster and email advertisements. They were required to
117 be physically active but did not need to have previous experience in strength testing. All
118 participants were free from musculoskeletal injury, had no previous history of spinal or trunk
119 injury, were able to adopt the testing positions, and were not pregnant. All participants gave
120 written informed consent following a full explanation of the study protocol and the rights of
121 participants were protected. Ethical approval was granted from the local ethics committee in
122 accordance with The Declaration of Helsinki.

123 Protocol

124 The study consisted of two testing sessions separated by seven days. A standardised and
125 graduated warm-up was conducted prior to testing. The warm-up consisted of five minutes on
126 a cycle ergometer maintaining a rate of perceived exertion of 6/10 effort, followed by five
127 minutes of hip, lumbar and thoracic spine mobility exercises. Finally, three sets of 15 second
128 front planks, side planks and glute bridges were completed. Participants completed three
129 submaximal efforts at 50%,75% and 90% of self-perceived maximal voluntary contraction in
130 each of the four testing positions prior to data collection to familiarise themselves with the
131 testing requirements.

132 Participants were positioned in prone, supine, left-sided recumbant and right-side recumbant
133 positions on an adjustable glute-hamstring raise machine (Pro-D Glute/Ham Hyper Station,
134 Pullum Sports, Leighton Buzzard, UK). Within each position, the participant was parallel to the
135 ground, with their feet secured within the foot supports of the glute-hamstring raise machine,
136 knees in five degrees flexion, arms folded across chest, hands resting on their opposing
137 acromion process, and iliac crests level with the edge of the glute-hamstring raise machine
138 (**FIGURE 1**). A 10 Hz fixed digital dynamometer (EasyForce digital dynamometer, Meloq,
139 Sweden) was attached to the participant using a harness and carabena system (**FIGURE 2**)
140 and connected to the base of the glute-hamstring raise machine with a ratchet strap. A box
141 was placed in front of the participant, allowing them to rest between contraction efforts.

142 For each position, testing consisted of three five-second isometric maximal voluntary
143 contractions (MVCs). Within each position, the participant maintained maximal comfortable
144 posterior pelvic tilt throughout. To minimise possible fatigue (Harding et al⁶), a 30-second rest
145 period was given between each trial, and a two-minute rest period was given between each
146 position (Mattiussi et al¹³). Testing position order was randomised for each participant, with
147 the same order repeated when conducting the retest to reduce systematic error and minimise
148 the effects of fatigue and potentiation on results. An assistant recorded scores to ensure
149 blinding of the primary tester from the results to reduce observer bias. The dynamometer was

150 zeroed between each trial. Peak force values were measured in kilograms and the mean and
151 maximum peak force value over three trials in each position was calculated.

152 Participants were briefed to “pull-up maximally against the dynamometer” prior to each
153 attempt. Each attempt was started by the lead author, telling the participant to adopt the
154 starting position and then counting down “3, 2, 1, pull” (Mattiussi et al¹³). In prone, participants
155 pulled up against the fixed digital-dynamometer, attempting to extend the spine. In supine,
156 participants pulled up against the fixed digital-dynamometer, attempting to flex the spine. In
157 left and right-side recumbent, participants pulled up against the fixed digital-dynamometer,
158 attempting to right and left side-flex the spine, respectively. Testing was stopped and an
159 additional trial was conducted if any compensatory patterns of movement were observed (e.g.
160 hyperextension through the lumbar spine), an inability to maintain the appropriate test position,
161 any pain was experienced, or the participant voluntarily discontinued the test.

162 Data Analysis

163 Following the completion of data collection, relative force was calculated by dividing the
164 absolute force by body mass. The mean \pm standard deviation (SD) of the absolute and relative
165 force was calculated from the three trials in each position. The maximum \pm standard deviation
166 (SD) of the absolute and relative force was also calculated from the mean of each participant’s
167 maximum trial in each position. In addition, strength ratios between opposing directions of
168 movement were calculated by dividing the mean absolute prone force by the mean absolute
169 supine force, and by dividing the mean absolute left-side force by the mean absolute right-
170 side force.

171 Statistical Analysis

172 Within-session (2, 1) and between-session (2, k) reliability were evaluated using ICCs
173 (Mokkink et al¹⁶; Weir³⁵), calculated using two-way random effects models, with 95%
174 confidence intervals. Shapiro-Wilk tests were used to verify the normality of data distribution.
175 Within-session reliability was calculated using the three trials in each position, collected during

176 the second testing session. Between-session reliability was calculated using the mean and
177 maximum score in each position over the two testing sessions. The ICCs were interpreted as
178 follows (Koo and Li¹⁰): *Poor* < 0.50, *Moderate* 0.50–0.75, *Good* 0.75–0.90, *Excellent* > 0.90.

179 The SEM was determined using the equation:

$$180 \quad SEM = SD_{baseline} \times \sqrt{1 - ICC_{between}}$$

181 The MDC was determined using the equation:

$$182 \quad MDC = 1.96 \times SEM \times \sqrt{2}$$

183 The CV was determined using the equation:

$$184 \quad CV = \frac{\sqrt{MSE}}{\bar{y}}$$

185 All statistical analysis was carried out using R (version 4.0.3, R Foundation for Statistical
186 Computing, Vienna, Austria). Significance was set at $p < .05$.

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196 **Results**

197 The characteristics of the participants were 10 male (age: 37.7 ± 9.7 years, height: $1.81 \pm$
198 0.1 m, weight: 79.1 ± 9.1 kg) and 8 female (age: 36.5 ± 8.5 years, height: 1.69 ± 0.1 m,
199 weight: 62.3 ± 11.3 kg).

200 Within-session reliability was *excellent* in all four positions (ICC 0.95–0.98), with relative
201 force MDC ranging from 14% to 18% and variability ranging from 5% to 7%. Between-
202 session reliability was *excellent* in all four-positions (ICC 0.98–0.99), with relative force MDC
203 ranging from 8% to 13% and variability ranging from 4% to 6%. Within and between-session
204 reliability statistics are presented in **TABLE 1**.

205 Descriptive statistics of absolute and relative force data across all testing positions are
206 presented in **TABLE 1**, whilst box plots of individual participant test-retest absolute and
207 relative force data are presented in **FIGURE 3**. The forces in the prone position across all
208 participants were almost two-fold that of all other positions (prone mean = 41.8 ± 17.7 kg),
209 whilst all other positions were similar (supine mean = 23.1 ± 10.8 kg; left mean 24.1 ± 10.1
210 kg; right mean = 21.9 ± 8.4 kg). The relative strength ratio of prone:supine position was 1.8
211 in males and 1.7 in females; whilst the left: right side-recumbant position strength ratio was
212 1.1 in males and 1.0 in females.

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220 **Discussion**

221 This study investigated the reliability, variability, SEM and MDC of fixed digital dynamometer
222 multi-planar trunk strength tests for the first time. The results demonstrated *excellent* within-
223 and between-session reliability ($ICC \geq 0.95$) with low variability ($CV \leq 7\%$) and MDC of up to
224 6.3kg for absolute and relative force across all four testing positions. Based on these results,
225 the testing protocol investigated in all four positions can be considered to provide consistent
226 measurements of isometric trunk muscle strength in both the sagittal and frontal planes. For
227 ease, practitioners may want to use only one measure of force (i.e., absolute or relative force)
228 in clinical practice due to comparable reliability and variability.

229 In line with previous investigations into fixed digital dynamometry for the assessment of
230 isometric strength of the shoulder ($ICC 0.91$), knee ($ICC 0.83$), and hip ($ICC 0.89$) (Trajković
231 et al³¹), we observed *excellent* reliability using the same method to assess multiplanar trunk
232 strength. These results were consistent, both within and between sessions, and across all four
233 testing positions. Furthermore, these results demonstrated higher between-session reliability
234 than when using a handheld dynamometer ($ICC 0.67-0.93$) (De Blaiser et al³) and similar
235 between-session reliability to using an isokinetic dynamometer ($ICC 0.87-0.95$) (Guilhem et
236 al⁵) when measuring trunk strength. This study, therefore, provides clinicians with a method
237 that is not only cost-effective, but is as reliable as gold-standard approaches, making it
238 preferable in applied environments.

239 The between-session MDC for absolute force ranged from 8% (prone) to 13% (right-side
240 recumbant) of the group mean during the four different positions of trunk strength; translating
241 to absolute values between 2.9 to 3.2 kg across all positions. The MDCs observed in the
242 present study are slightly greater than those previously reported using isokinetic dynamometry
243 (9%) (Guilhem et al⁵), and considerably greater than similar research using a bespoke
244 measurement system (3.1 N) (Loss et al¹¹). It is plausible that the lower MDCs observed in
245 the aforementioned studies are explained by the equipment used, which restricted movement
246 to a single plane and involved more points of stabilisation, making them more robust against

247 small variations in participant position. Conversely, the between-session MDCs of trunk testing
248 using handheld dynamometry were larger than those observed in this study (5.2–7.5 kg;
249 Kahraman et al⁹). Studies employing handheld dynamometry to measure trunk strength have
250 failed to adequately stabilise participants, with fixation either not being used at all or only being
251 used at one region of the body potentially leading to erroneous results (e.g. across the hips)
252 (Newman et al¹⁹). The present method, therefore, offers a middle ground between the
253 excessive degrees-of-freedom present using a handheld dynamometry approach, and the low
254 degrees-of-freedom but low practicality of isokinetic dynamometry/bespoke equipment
255 approaches.

256 Peak forces in this study are approximately 10% lower than when testing with an isokinetic
257 dynamometer (Zouita et al³⁶). This may be explained by the reduced fixation employed in this
258 study compared to when using an isokinetic dynamometer, resulting in decreased force
259 production. Increased fixation during strength testing has been shown to lead to increased
260 force output when testing other regions of the body (Michailov et al¹⁵), however, it may curtail
261 specificity and compromise the clinical applicability of the test. In contrast, the testing method
262 chosen may not isolate the trunk musculature, and, as such, there may be contributions from
263 other muscles within the body. This is more akin to real life where trunk muscles work in
264 combination with muscles of the upper and lower limb to provide stability and transfer force
265 through the kinetic chain (Martin et al¹²; Rodriguez-Perea²⁶). The descriptive data set in this
266 study, within the specific population recruited, provides insight into trunk strength and the
267 ratios between opposing positions. The trunk extensors (prone position) demonstrated 1.7 and
268 1.8 times the force of the trunk flexors (supine position) in females and males respectively.
269 This is consistent with past research that has shown the trunk extensors are stronger than the
270 trunk flexors (Moussa et al¹⁸; Reyes-Ferrada²⁵).

271 *Strengths and Limitations*

272 A strength of this study is the participant recruitment process. Unlike much research in the
273 sports science literature (Paul et al²⁰), it adopted a mixed sample of both males and females;

274 improving the generalisability of the results. This has been a limitation of recent research
275 investigating trunk strength measurements (Rodriguez-Perea²⁸; Reyes-Ferrada²²). Also, the
276 four testing positions ensured multi-planar trunk maximum strength assessment, a testing
277 protocol lacking in the current literature base (Althobaiti et al¹).

278 There are several limitations of this study. Firstly, participants were positioned using visual
279 observation. Accurately measuring spinal position is complex, requiring specific equipment
280 (Sonvico et al²⁹). Further research may wish to implement more stringent measures of spinal
281 position through technological advancements, such as the use of sensors and accelerometers
282 (Sonvico et al²⁹). However, the decision was made to aid the clinical applicability of this
283 methodology and translate best to a practical setting in which time is finite and resources are
284 limited. A further limitation of this set-up is that these positions do not isolate the trunk
285 musculature, and, as such, there will be contributions from the entire kinetic chain. For
286 example, during the supine position, the hip flexors will contribute to force generation and
287 during the prone position, there will be involvement of the hip extensors (Moussa et al¹⁸).
288 Therefore, future research could use the fixed digital dynamometer in a different static position
289 to determine if a better method exists to measure trunk strength. Thirdly, practitioners should
290 be cautious when extrapolating the findings beyond the current population group. Future
291 research could perform the same testing protocol in other populations, for example individuals
292 with low back pain, elite athletes or older adults. Lastly, large differences in between-
293 participant SD of strength were observed indicating minimal homogeneity across the group
294 which may have affected the MDC calculation. A more homogeneous group with more similar
295 physical qualities may lead to smaller MDC values.

296 *Practical Applications*

297 The protocol adopted in this study was quick to administer and easy to standardise, making it
298 appealing for practitioners working in clinical practice. Thereby allowing the effects of trunk
299 strength training or rehabilitation to be better understood. The isometric nature of contractions
300 may also mean this assessment method is better tolerated in individuals with low back pain

301 than more dynamic through range maximum contractions (Rodriguez-Perea²⁸). Based on the
302 relative ease of testing, low-cost of equipment, excellent reliability and competitive MDC
303 values, these results provide a strong justification for the use of the present methodology in
304 future research and practice.

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316 **Conclusion**

317 This is the first study to investigate the within- and between-session reliability, variability, and
318 MDC of multiplanar isometric trunk strength testing using a fixed digital dynamometer. Based
319 on the results of this study, the fixed digital dynamometer is a reliable tool to assess multi-
320 planar trunk strength in the four chosen positions. In addition, when interpreting for a
321 meaningful change, absolute values of between 8–13% (or 2.9 to 3.2 kg) of the group mean
322 between the four trunk testing positions can be used as benchmarks. This offers clinicians a
323 readily available, highly portable and cost-effective method of assessing all four quadrants of
324 trunk strength. Practically, simple and reliable assessment of trunk strength will facilitate the
325 identification of insufficient trunk strength, allow practitioners to track longitudinal changes in
326 trunk strength, and aid in trunk-specific performance and rehabilitation programming.

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350 **Declaration of Interest Statement:**

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484 **TABLE 1. Descriptive statistics, and within- and between-session reliability results for absolute and relative force tests.**

Reliability	Variable	Aggregation	Position	Mean Force ± Standard Deviation			ICC (95% CI)	CV (%)	SEM (kg)	MDC	
				Session / Trial 1	Session / Trial 2	Session / Trial 3				kg	%
Between-Session	Absolute	Maximum	Prone	43.3 ± 18.0	43.6 ± 18.4	-	1.00 (0.99–1.00)	4%	1.1	3.2	7%
			Supine	24.6 ± 10.9	24.4 ± 11.0	-	0.99 (0.98–1.00)	5%	0.9	2.5	10%
			Left	24.8 ± 10.9	26.1 ± 10.6	-	0.99 (0.96–1.00)	5%	1.2	3.2	13%
			Right	22.9 ± 9.1	23.8 ± 8.8	-	0.98 (0.96–0.99)	7%	1.2	3.4	14%
		Mean	Prone	41.5 ± 17.9	42.1 ± 17.6	-	1.00 (0.99–1.00)	4%	1.2	3.2	8%
			Supine	23.2 ± 10.7	23.0 ± 11.1	-	1.00 (0.99–1.00)	5%	0.7	2.0	9%
			Left	23.5 ± 10.0	24.8 ± 10.2	-	0.99 (0.96–1.00)	5%	1.0	2.7	11%
			Right	21.4 ± 8.5	22.4 ± 8.4	-	0.98 (0.96–0.99)	6%	1.1	2.9	13%
	Relative	Maximum	Prone	0.60 ± 0.23	0.61 ± 0.23	-	0.99 (0.99–1.00)	4%	0.017	0.047	8%
			Supine	0.34 ± 0.14	0.34 ± 0.14	-	0.99 (0.98–1.00)	5%	0.012	0.035	10%
			Left	0.34 ± 0.13	0.36 ± 0.12	-	0.98 (0.94–0.99)	5%	0.016	0.044	13%
			Right	0.32 ± 0.10	0.33 ± 0.10	-	0.97 (0.94–0.99)	7%	0.016	0.045	14%
		Mean	Prone	0.58 ± 0.23	0.58 ± 0.22	-	0.99 (0.99–1.00)	4%	0.017	0.048	8%
			Supine	0.32 ± 0.13	0.32 ± 0.14	-	0.99 (0.99–1.00)	5%	0.010	0.028	9%
			Left	0.32 ± 0.11	0.34 ± 0.11	-	0.99 (0.94–0.99)	5%	0.014	0.038	12%
			Right	0.30 ± 0.10	0.31 ± 0.10	-	0.98 (0.95–0.99)	6%	0.014	0.038	13%
Within-Session	Absolute	-	Prone	41.6 ± 18.6	42.3 ± 16.7	42.4 ± 17.8	0.98 (0.97–0.99)	6%	2.3	6.3	15%
			Supine	23.4 ± 11.3	22.8 ± 11.4	22.9 ± 10.7	0.98 (0.97–0.99)	6%	1.4	4.0	17%
			Left	24.5 ± 9.7	24.5 ± 10.1	25.3 ± 10.9	0.98 (0.95–0.99)	6%	1.6	4.4	18%
			Right	22.3 ± 8.3	22.5 ± 8.7	22.3 ± 8.5	0.97 (0.94–0.98)	7%	1.5	4.2	19%
	Relative	-	Prone	0.58 ± 0.24	0.59 ± 0.21	0.59 ± 0.22	0.98 (0.97–0.99)	5%	0.030	0.082	14%
			Supine	0.33 ± 0.14	0.32 ± 0.14	0.32 ± 0.13	0.98 (0.95–0.99)	7%	0.021	0.058	18%
			Left	0.34 ± 0.11	0.34 ± 0.11	0.35 ± 0.12	0.96 (0.93–0.98)	7%	0.022	0.061	18%
			Right	0.31 ± 0.10	0.31 ± 0.10	0.31 ± 0.10	0.95 (0.92–0.98)	7%	0.020	0.057	18%

485 *Note:* ICC, Intraclass Correlation Coefficient; CV, Coefficient of Variation; SEM, Standard Error of Measurement; MDC, Minimal Detectable Change; CI, Confidence Interval.

486 **FIGURE 1.** Trunk Testing Positions. A - Prone, B - Supine, C - Left-Side Recumbant, D -Right-Side Recumbant

487 **FIGURE 2.** Harness and Carabena System (Power Pull, Perform Better)

488 **FIGURE 3.** Box plots of individual test-retest Mean Relative (A), Max Relative (B), Mean Absolute (C) and Max Absolute (D) force data within
489 each testing position.

490 *Note:* BW, bodyweight; kg, kilograms