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1 **ASSESSING MUSCLE STRENGTH ASYMMETRY VIA A UNILATERAL STANCE**
2 **ISOMETRIC MID-THIGH PULL**

3
4 *Original Investigation*

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6
7 Thomas Dos'Santos#, Christopher Thomas, Paul, A. Jones & Paul Comfort

8
9 Human Performance Laboratory, Directorate of Sport, Exercise, and Physiotherapy,
10 University of Salford, Greater Manchester, United Kingdom

11
12 Corresponding Author: Thomas Dos'Santos

13
14 Telephone: +447961744517

15 Email: t.dossantos@hotmail.co.uk

16
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51 Abstract

52

53 **Purpose:** The purpose of this study was to investigate the within-session reliability of
54 bilateral and unilateral stance isometric mid-thigh pull (IMTP) force-time characteristics
55 including peak force (PF), relative PF and impulse at time bands (0-100, 0-200, 0-250 and 0-
56 300 ms); and to compare isometric force-time characteristics between right and left and
57 dominant (D) and non-dominant (ND) limbs. **Methods:** Professional male Rugby league and
58 multi-sport collegiate male athletes ($n=54$, age 23.4 ± 4.2 years, height 1.80 ± 0.05 m, mass:
59 88.9 ± 12.9 kg) performed 3 bilateral IMTP trials, and 3 unilateral stance IMTP trials per leg
60 on a force plate sampling at 600 Hz. **Results:** Intraclass correlation coefficients (ICC) and
61 coefficients of variation (CV) demonstrated high-within session reliability for bilateral and
62 unilateral IMTP PF (ICC =.94, CV = 4.7–5.5%). Lower reliability measures and greater
63 variability were observed for bilateral and unilateral IMTP impulse at time bands (ICC =.81-
64 .88, CV =7.7-11.8%). Paired sample t-tests and Cohen's d effect sizes revealed no significant
65 differences for all isometric force-time characteristics between right and left limbs in
66 collegiate male athletes ($p >.05$, $d \leq 0.32$) and professional rugby league players ($p >.05$, d
67 ≤ 0.11), however significant differences were found between D and ND limbs in male
68 collegiate athletes ($p <.001$, $d = 0.43-0.91$) and professional rugby league players ($p <.001$, d
69 $= 0.27-0.46$). **Conclusion:** This study demonstrated high within-session reliability for
70 unilateral stance IMTP PF; revealing significant differences in isometric force-time
71 characteristics between D and ND limbs in male athletes.

72

73 **Keywords:** peak force, impulse, imbalance, reliability

74

75 Introduction

76

77 Muscle strength asymmetry (MSA) refers to the relative strength differences and deficits
78 between limbs,¹ with a strength discrepancy of 10-15% or more between two sides
79 considered to represent a potentially problematic asymmetry.² Higher MSA indexes have
80 been suggested to place athletes at a greater risk of injury,^{3 4,5} conversely researchers have
81 demonstrated no connection between MSA and injury.^{6,7} However, there is no specific value
82 in the literature that represents the threshold between injured and non-injured athletes, or
83 values that definitively identify an increased injury risk in athletes.⁸ It should be noted that
84 asymmetries may be a positive adaptation of the sport, developed by specific sporting
85 demands.⁹ In terms of athletic performance previous studies have also shown MSA can
86 negatively impact performance during change of direction,¹⁰ vertical jumping,^{11, 12} and
87 kicking.¹³ However, asymmetry index values for athletic performance measures have yet to
88 be established.¹⁴

89

90 Muscle strength asymmetry has typically been assessed in athletes via isokinetic
91 dynamometry,^{3,14} vertical jump,¹² and multidirectional jump and hop tasks;¹⁵ with research
92 suggesting that the magnitude of MSA are task dependant.^{14, 15} More recently researchers
93 have investigated isometric bilateral asymmetries through isometric squat^{13, 16} and isometric
94 mid-thigh pull (IMTP)^{11, 17-19} assessments via a dual force plate system. Interestingly,
95 isometric asymmetrical differences have been observed between dominant (D) and non-
96 dominant (ND) limbs for peak force,^{11, 17-19} and time-specific force values,^{18, 19} with
97 researchers reporting larger asymmetries in weaker athletes¹⁶⁻¹⁸ and female athletes^{18, 19} in
98 comparison to stronger athletes. Moreover, larger asymmetries have been associated with
99 lower jump heights and lower peak power in loaded and unloaded jumps.¹¹ However, block
100 periodised strength training has been shown to reduce bilateral asymmetries in weaker

101 athletes.¹⁶ Therefore, the assessment of lower limb MSA allows scientists and practitioners to
102 monitor and identify higher imbalanced athletes to subsequently design effective training
103 programs to reduce strength imbalances. This could potentially reduce risk of injury and
104 improve athletic performance.

105
106 Jumping, sprinting and change of direction (COD) movements are unilateral, requiring
107 unilateral propulsive force production. Researchers have investigated unilateral force
108 production through unilateral jump assessments in relation to athletic performance tasks^{10, 20}
109 and to investigate imbalances between lower limbs.^{15, 21} To our knowledge, previous
110 investigations have only assessed unilateral isometric force-time characteristics via an
111 unilateral isometric squat^{13, 22, 23} demonstrating high reliability measures. However, as IMTP
112 assessments are becoming more common in testing batteries in various athletic populations,^{18,}
113 ²⁴ and yield high reliability and low measurement error in force-time variables;^{24, 25} it is
114 somewhat surprising that a unilateral stance IMTP has yet to be investigated for assessing
115 MSA.

116
117 As previously stated bilateral asymmetries have been established during bilateral IMTP
118 assessments via a dual force plate system,^{11, 18, 19} however a unilateral stance IMTP would
119 allow direct comparisons between left and right limbs to establish any MSA indexes and the
120 identification of D and ND limbs. Furthermore, given the unilateral force production
121 requirements of sprinting, jumping and COD movements, arguably a unilateral stance IMTP
122 would be more specific to these dynamic sporting movements. Although the relationship of
123 MSA and injury risk remains inconclusive, from a performance perspective it would be
124 advantageous being equally proficient at producing force in both lower limbs,¹⁴ given the
125 unpredictable nature of multidirectional sports where athletes must change direction, jump
126 and land off either limb in response to stimuli.

127
128 The aims of this study were firstly to assess the within-session reliability of bilateral and
129 unilateral IMTP force-time characteristics (Peak force [PF], relative PF, impulse at time
130 bands 0-100, 0-200, 0-250, 0-300 ms). Secondly, to compare left and right and D and ND
131 limbs to determine if any significant differences and imbalances were present between limbs.
132 Thirdly, to establish normative MSA ranges for male collegiate athletes and professional
133 male rugby league players. It was hypothesized that the unilateral IMTP would demonstrate
134 high reliability, similar to the bilateral IMTP. Further, it was hypothesized that no significant
135 differences will be found in isometric force-time characteristic between left and right limbs,
136 but that significant differences would be observed between D and ND limbs.

137 138 **Methods**

139 140 **Subjects**

141 54 male athletes consisting of 35 professional male rugby league players (age 24.2 ± 4.8
142 years, height 1.81 ± 0.06 m, mass 94.5 ± 11.2 kg) and 19 collegiate male athletes (soccer $n=7$,
143 rugby $n=2$, boxing $n=2$, weightlifting $n=2$, water polo $n=1$, cricket $n=1$, judo $n=2$, American
144 football $n=2$) (age 21.7 ± 2.3 years, height 1.80 ± 0.05 m, mass 78.4 ± 7.9 kg) provided
145 informed consent to participate in this study which was approved by the institutional review
146 board. All subjects were familiar with the IMTP and possessed >2 years resistance training
147 experience. At the time of testing, the rugby athletes were at the end of pre-season and
148 collegiate athletes were currently in season.

149 150 **Design**

151 A within subjects design was used to determine any significant differences in isometric force-
152 time characteristics (PF, relative PF, impulse at time bands 0-100, 0-200, 0-250, 0-300 ms)
153 between left and right and D and ND limbs during the unilateral IMTP; and to determine
154 MSA indexes between limbs. Subjects performed three maximal bilateral IMTPs, and 3
155 unilateral stance IMTP trials per leg on a force plate sampling at 600 Hz. Within-session
156 reliability was assessed for all isometric force-time characteristics for both bilateral and
157 unilateral IMTPs.

158

159 **Procedures**

160

161 **Pre-isometric warm up**

162 All subjects performed a standardized warm-up outlined in previous research,²⁶ comprising of
163 5 minutes of dynamic stretching before advancing to dynamic mid-thigh clean pulls. One set
164 of 5 repetitions was performed with an empty barbell (Werksan Olympic Bar, Werksan,
165 Moorsetown, NJ, USA) followed by 3 bilateral isometric efforts at perceived intensities of
166 50%, 70%, and 90% of maximum effort, interspersed with 1-minute recoveries.

167

168 **Bilateral and unilateral isometric mid-thigh pull protocol**

169 Bilateral IMTP testing followed similar protocols used in previous research.²⁷ The IMTP
170 testing was performed on a portable force plate sampling at 600 Hz (400 Series Performance
171 Force Plate, Fitness Technology, Adelaide, Australia) using a portable IMTP rack (Fitness
172 Technology, Adelaide, Australia). Sampling as low as 500 Hz has been shown to produce
173 high reliability measures for isometric force-time variables.²⁶ The force plate was interfaced
174 with computer software [Ballistic Measurement System (BMS)] which allowed direct
175 measurement of force-time characteristics.

176 For the bilateral stance IMTP testing, a collarless steel bar was positioned to correspond to
177 the athlete's second-pull power clean position²⁴ just below the crease of the hip. The bar
178 height could be adjusted (3 cm increments) at various heights above the force plate to
179 accommodate different sized athletes. Athletes were strapped to the bar in accordance to
180 previous research²⁸ and positioned in their self-selected mid-thigh clean position established
181 in the familiarization trials whereby feet were shoulder width apart, knees were flexed over
182 the toes, shoulders were just behind the bar, and torso was upright.²⁶ Researchers have
183 demonstrated that differences in knee and hip joint angles during the IMTP do not influence
184 kinetic variables²⁵ justifying the self-selected preferred mid-thigh position. All subjects
185 received standardized instructions to pull as fast and as hard as possible and push their feet
186 into the force plate until being told to stop, as these instructions have been shown to be
187 optimal in producing maximum PF and RFD results.²⁸ Once the body was stabilised (verified
188 by watching the subject and force trace) the IMTP was initiated with the countdown "3, 2, 1
189 pull," with subjects ensuring that maximal effort was applied for 5 seconds based on previous
190 protocols;^{24, 28} data was collected for a duration of 8 seconds. Minimal pre-tension was
191 allowed to ensure there is no slack in the body prior to initiation of pull. Verbal
192 encouragement was given for all trials and subjects. Subjects performed a total of 3 bilateral
193 maximal effort trials and interspersed with 2-minute recoveries.

194

195 Unilateral stance IMTP testing followed the same procedures outlined for bilateral IMTP
196 testing however was only performed with one foot on the force platform with the other limb
197 flexed 90° at the knee. Subjects were positioned at the same hip and knee joint angle
198 established during bilateral testing. Subjects were instructed to maintain balance and pull as
199 fast and as hard as possible and pushing their single foot into the force plate. Subjects

200 performed a total of six unilateral maximum effort trials (3 with left and right limbs each) in
201 an alternating order, interspersed with 2-minute recoveries. Any trials whereby subjects lost
202 balance were excluded, and further trials were performed after a further 2-minute rest period.

203

204 **Isometric Force-Time Curve Assessment**

205 Isometric force-time data was analysed via BMS software. The maximum force recorded
206 during the 5-second bilateral and unilateral IMTP trials was reported as PF. Relative PF was
207 calculated PF / body mass. Impulse at 100 (IP 100), 200 (IP 200), 250 (IP 250) and 300 (IP
208 300) ms were also calculated (area under the force-time curve for each window) from onset
209 of contraction (40 N threshold) and have demonstrated high reliability measures.^{25,27}

210 **Statistical Analyses**

211 Statistical analysis was performed using SPSS software version 22 (SPSS, Chicago, Ill, USA)
212 and a custom reliability spreadsheet.²⁹ Normality was confirmed for all variables using a
213 Shapiro Wilks-test. Within-session reliability was assessed via intraclass correlation
214 coefficients (ICC), 95% confidence intervals (CI), coefficient of variation (CV), typical error
215 of measurement (TE) expressed as CV between the three trials for each dependant variable
216 using a custom spreadsheet²⁹ and percentage change in mean. The CV was calculated based
217 on the mean square error term of logarithmically transformed data.²⁹ Minimum acceptable
218 reliability was determined with an ICC > 0.7 and CV < 10%.^{30,31} Mean ± SD were calculated
219 for all dependent variables.

220

221 Asymmetry index (imbalance between right and left limbs) was calculated by the formulae
222 (right leg – left leg/ right leg × 100) for unilateral IMTP variables.⁹ Asymmetry index for D
223 and ND limbs was calculated by the formulae (dominant leg – non dominant leg/ dominant
224 leg x 100) for unilateral IMTP variables, in accordance to previous research.⁹ Limb
225 dominance was defined as the limb that produced the highest isometric force-time value. To
226 assess the magnitude of differences in force-time characteristics between limbs in male
227 collegiate and professional rugby league players, paired sample t-tests and Cohen's *d* effect
228 sizes were implemented. Effect sizes were calculated by the formula Cohen's $d = M - M2/\sigma$
229 pooled³² and interpreted as trivial (<0.19), small (0.20–0.59), moderate (0.60–1.19), large
230 (1.20–1.99), and very large (2.0–4.0).³³ The criterion for significance was set at $p \leq 0.05$.

231 **Results**

232

233 Intraclass correlation coefficients and CV demonstrated high within-session reliability for
234 bilateral and unilateral IMTP PF (ICC = .94, CV = 4.7 – 5.5%) (Table 1). Lower reliability
235 measures and greater variability were observed for bilateral and unilateral IMTP impulse at
236 time bands (ICC = .81 - .88, CV = 7.7 - 11.8%) (Table 1). Unilateral IMTP left and right IP
237 100 met minimum acceptable reliability criteria (ICC = .83 - .87, CV = 9.3 – 9.5%); **however**
238 **IP 200, IP 250 and IP 300 demonstrated a greater level of variance than has previously been**
239 **recommended (ICC= .82 - .88, CV = 10.3 – 11.6%).**³² Descriptive statistics for bilateral and
240 unilateral IMTP force-time characteristics are presented in Tables 2 and 3. Unilateral IMTP
241 descriptive statistics, MSA indexes and ESs are presented in Tables 2 and 3.

242

243

Insert Table 1 around here

244

245 **Professional Male Rugby League Players**

246 No significant differences ($p > .05$, $d \leq 0.11$) between right and left limbs were observed for
247 all isometric force-time characteristics; with trivial differences between limbs (Table 2).

248 Conversely, small significant differences ($p < .001$, $d = 0.27 - 0.46$) were found between D
249 and ND limbs for all isometric force-time characteristics (Table 3).

250

251 Collegiate Male Athletes

252 No significant differences ($p > .05$, $d \leq 0.32$) between right and left limbs were observed for
253 all isometric force-time characteristics; with trivial to small differences between limbs (Table
254 2). Conversely, small to moderate significant differences ($p < .001$, $d = 0.43 - 0.91$) were
255 found between D and ND limbs for all isometric force-time characteristics (Table 3).

256

257 **Insert Table 2 around here**

258

259 **Insert Table 3 around here**

260

260 Discussion

261

262 The aims of this study were to assess the within-session reliability of bilateral and unilateral
263 stance IMTP force-time characteristics and to determine if significant differences in isometric
264 strength were present between lower limbs in male collegiate and male professional rugby
265 league athletes. The results from this study demonstrated high-within session reliability for
266 bilateral and unilateral stance IMTP PF meeting minimum acceptable reliability criteria.
267 Lower reliability measures and greater variability were observed for unilateral IMTP IP 100,
268 however still met minimum acceptable reliability criteria. **Conversely, unilateral IMTP IP
269 200, IP 250 and IP 300 demonstrated a greater level of variance than has previously been
270 recommended (Table 1).**³² Trivial to small non-significant differences were observed between
271 force-time characteristics for right and left limbs in collegiate and professional rugby league
272 players (Table 2). However, small to moderate significant differences were revealed between
273 D and ND limbs in male collegiate athletes and small significant differences between D and
274 ND in professional rugby league players (Table 3). These findings are in agreement with our
275 hypotheses.

276 The bilateral IMTP has been reported to be highly reliable with a low measurement error.^{24,}
277 ^{25, 27} Traditionally, IMTP assessments have been performed bilaterally, with asymmetries
278 having only been established with the use of dual force platforms during bilateral IMTPs.^{11, 17,}
279 ¹⁸ To our knowledge, this study is the first to investigate a unilateral stance IMTP for the
280 assessment of MSA indexes, demonstrating high reliability measures for isometric PF and
281 lower reliability measures for impulse at time bands (Table 1). Further, significant differences
282 were also observed between D and ND limbs (Table 3) for all isometric force-time
283 characteristics. Therefore, this study revealed high within-session reliability for the
284 assessment of unilateral stance IMTP PF and significant differences in force-time
285 characteristics between D and ND limbs in male athletes (Table 3). However, a limitation of
286 the present study is only the within-session reliability of the unilateral stance IMTP force-
287 time characteristics was assessed, therefore, further research is required assessing between
288 session test-retest reliability of the unilateral stance IMTP.

289

290 As previously stated limited studies have inspected unilateral multi-joint isometric strength
291 through unilateral isometric squat assessments.^{13, 22, 23} Hart et al²² reported very high
292 reliability measures of unilateral squat isometric PF (ICC = .96 – .98, CV = 3.6 - 4.7%) in 11
293 male athletes. Spiteri et al²³ demonstrated similar reliability measures for unilateral isometric
294 squat PF (ICC = .95, CV = 5.5 – 7%) in 12 male and 12 female athletes. Specifically, the

295 present study demonstrated comparable reliability measures for unilateral IMTP PF (ICC =
296 .94, CV = 4.7 – 5.0%) to the above-mentioned studies in a large male sample (n = 54).
297 Moreover, athletes may experience less discomfort when performing a unilateral IMTP in
298 comparison to a unilateral isometric squat, due to pulling an immovable bar in comparison to
299 pushing against an immovable bar positioned on the upper back (mid trapezius) during
300 isometric squats. Consequently, the unilateral stance IMTP demonstrates high within-session
301 reliability for PF assessments, with further research required into the between session
302 reliability of unilateral PF.

303 This study is the first to inspect impulse at time bands (0-100, 0-200, 0-250, 0-300 ms) during
304 unilateral stance IMTP assessments, demonstrating lower within-session reliability (ICC =
305 .82 – .88, CV = 9.3 - 11.6%) and greater variability in contrast to PF reliability measures.
306 Excluding IP 100, all unilateral stance impulse at time bands **demonstrated a greater level of**
307 **variance than has previously been recommended.**³² Dynamic tasks such as sprinting, jumping
308 and changing direction are heavily dependent on an athlete’s capability to rapidly apply
309 unilateral force over short time intervals,^{23, 27} therefore the ability to assess an athlete’s
310 unilateral force and impulse production capabilities via the unilateral stance IMTP may allow
311 practitioners and scientists to identify any deficiencies in force production in specific limbs
312 and also monitor the effectiveness of training interventions. Although it should be
313 acknowledged that isometric and dynamic tasks are different. Our results indicate that the
314 unilateral IP 100 demonstrates acceptable reliability, although practitioners should be aware
315 greater variability may be observed when assessing impulse at alternative time bands (Table
316 1).

317 No significant differences were observed between left and right limbs for isometric force-
318 time characteristics in collegiate male athletes ($p > .05$, $d \leq 0.32$) and professional rugby
319 league players ($p > .05$, $d \leq 0.11$). However, significant differences were observed when
320 comparing D and ND limbs in male collegiate athletes ($p < 0.001$, $d = 0.43 - 0.91$) and
321 professional rugby league players ($p < .001$, $d = 0.27 - 0.46$); highlighting that isometric
322 strength deficits between lower limbs are present in male athletes. Future research is required
323 establishing isometric MSA indexes in female athletes.

324

325 ****Insert Figure 1 around here****

326 ****Insert Figure 2 around here****

327

328

329 **The magnitudes of asymmetry in collegiate male athletes (6.2 ± 4.8 to $11.5 \pm 9.5\%$) and**
330 **professional rugby league players (5.1 ± 3.8 to $9.6 \pm 8.6\%$) are presented in Table 3;**
331 **individual PF imbalances are also illustrated in Figures 1 and 2. It should be noted that the**
332 **that larger asymmetry values observed in the collegiate male athletes could be attributed to a**
333 **heterogenous mixed sporting sample that contained athletes from sports where there are**
334 **specific asymmetrical movement demands for example soccer, boxing and cricket which may**
335 **result in the development of strength asymmetries.**^{34, 35} **For example, Figure 2 illustrates the**
336 **individual PF imbalance between D and ND limbs in collegiate male athletes, showing the**
337 **boxers in this cohort demonstrated higher asymmetries in contrast to the other athletes from**
338 **different which elevates the mean imbalance of this cohort.** It should also be acknowledged
339 the results of this present study are only applicable and representative of the athletes at the
340 specific time of the season they were tested; and are therefore likely to change over a

341 competitive season. Researchers have shown seasonal changes in fitness and strength
342 characteristics throughout a season^{36, 37} and the specific training phase has also shown to
343 influence jump performance.³⁸ However, to our knowledge no literature exists investigating
344 isometric strength asymmetries throughout a competitive season. Therefore, a future direction
345 of research is to investigate seasonal variations in MSA as measured by the IMTP.

346 A strength discrepancy of 10-15% between limbs is considered to represent a potentially
347 problematic asymmetry.² Although, no literature is available to substantiate this claim,⁸ it is
348 likely that the typical magnitude of MSA may vary between different muscle strength
349 qualities for example concentric, eccentric, isometric and dynamic strength,^{14, 15} and between
350 different athlete populations.³⁵ Our findings provide normative MSA data for unilateral IMTP
351 kinetics in different populations (Table 3). Athletes who demonstrate MSA greater than the
352 values in Table 3 could therefore be considered asymmetrical.

353

354 Asymmetries during IMTP have only been established bilaterally with each foot on a separate
355 force plate, with researchers observing asymmetries in isometric force time-characteristics in
356 male and female athletes.^{11, 17-19} Further, research suggests that weaker athletes display
357 greater asymmetries in isometric force-time characteristics in comparison to stronger athletes
358 during bilateral IMTPs^{17, 18} and bilateral isometric squats¹⁶ which may have a detrimental
359 impact on vertical jumping performance.¹¹ Block periodised bilateral strength training has
360 been reported to reduce bilateral asymmetries in weaker athletes;¹⁶ highlighting the
361 importance of maximising athletes bilateral strength to reduce the magnitude of bilateral
362 MSA. It is unknown if this would be the case for unilateral IMTP MSA, thus future
363 investigations are required determining the impact of strength training on unilateral IMTP
364 MSA.

365

366 It should be noted that above-mentioned studies have inspected asymmetries during bilateral
367 isometric squats and IMTPs and is therefore not a direct assessment of an isolated limb's
368 force production capabilities. Consequently, a unilateral stance IMTP would allow the direct
369 assessment of multi-joint isometric force production of a specific limb replicating unilateral
370 stance of sprint, jumps and COD supported by the high reliability shown in the current
371 findings. This will also help scientists and practitioners assess strength deficits between limbs
372 and identify normative MSA values for athletic populations to benchmark standards in
373 monitoring and strength assessments. Further, from a rehabilitation perspective a unilateral
374 stance IMTP could be implemented to assess an athlete's isometric strength pre- and post-
375 injury to determine the effectiveness training interventions and establish return to play
376 criteria.

377

378 The impact of MSA on injury risk in athletes remains inconclusive;⁸ however from a
379 performance perspective it would be advantageous to be equally proficient in force
380 production between limbs,¹⁴ due to the unilateral requirements of sprinting, jumping, landing
381 and change of directions. Previous studies have shown strength deficits between limbs can
382 negatively impact performance during change of direction,¹⁰ vertical jumping,^{11, 12} and
383 kicking.¹³ Our results revealed significant differences in unilateral IMTP force-time
384 characteristics between D and ND limbs in male athletes. However the implications of

385 unilateral IMTP MSA on dynamic performance such as jumping and COD is unknown, thus
386 is an area of further research.

387

388 **Practical Applications**

389 Overall, this study confirmed that the unilateral stance IMTP produces high within-session
390 reliability for PF and IP 100 also met minimum reliability criteria. Furthermore, small to
391 moderate significant differences were observed between D and ND limbs for all isometric
392 force-time characteristics with greater magnitudes of asymmetry of MSA in male collegiate
393 athletes in comparison to professional rugby players. Male athletes with isometric force-time
394 characteristics asymmetries greater than the **mean plus the SD of the normative MSA indexes**
395 **presented in Table 3** maybe considered asymmetrical. Practitioners and scientists should
396 therefore consider assessing athlete's unilateral isometric force production capabilities via a
397 unilateral stance IMTP. This would permit the direct assessment of multi-joint isometric
398 force production of the lower limbs replicating the unilateral stance of sprinting, jumping and
399 COD; allowing practitioners to identify strength deficits between limbs so subsequent
400 training programmes can be implemented to reduce the deficit which may reduce the
401 likelihood of injury and improve athletic performance. From a rehabilitation perspective a
402 unilateral stance IMTP would allow comparisons of lower limb strength and pre- and post-
403 injury and also monitor the effectiveness of training interventions.

404 **Conclusion**

405 Bilateral and unilateral stance IMTP assessments demonstrated high within-session reliability
406 for PF and lower although acceptable reliability measures for IP 100. Impulse at time bands
407 (0-200, 0-250 and 0-300 ms) **demonstrated a greater level of variance than has previously**
408 **been recommended**. No significant differences were observed between left and right limbs
409 during unilateral stance IMTP for male collegiate and rugby league players however
410 significant differences were revealed for all isometric force-time characteristics between D
411 and ND limbs. Future research should focus on the effect of strength training on the
412 magnitude of unilateral stance IMTP asymmetry and effect of isometric MSA on athletic
413 performance.

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