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1 Title:

2 Validity of a contact mat and accelerometric system to assess countermovement jump from
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4

5 Submission type: Original investigation

6

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20 Running head: Validation of systems for CMJ

21

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36

37 **Abstract**

38 Countermovement jump (CMJ) height is an important parameter in physical performance.
39 This study compared CMJ height measured using ChronoJump contact mat (CJ), and
40 Myotest accelerometer (MT) systems with a force platform (FP). Thirty recreationally-active
41 adults (32.1 ± 10.4 years, 75.9 ± 12.0 kg, 173.2 ± 6.3 cm) completed a CMJ protocol where
42 height was simultaneously recorded using the three systems. CJ and MT measures were
43 strongly and significant correlated ($r = 0.65, 0.66$, respectively; $p < 0.05$) with FP. CJ-derived
44 measures were not significantly different to FP measures ($p > 0.05$), yet MT-derived
45 measures were significantly different from those obtained using the FP ($p < 0.05$). Systematic
46 bias was observed between FP and the CJ and between FP and MT. This study demonstrate
47 the validity of CJ and MT systems for the assessment of CMJ height. Systematic bias and
48 between-device differences in measurement should be considered when interpreting and
49 comparing data from these devices.

50

51 **Keywords:** accelerometry; countermovement jump; performance; force plate

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57 Introduction

58 Assessment of lower limb functional performance is important in athletic, and non-
59 athletic populations. A commonly used measure of lower limb functional performance is the
60 countermovement jump (CMJ) (Comfort, Stewart, Bloom, & Clarkson, 2014; Fernandez-
61 Santos, Ruiz, Cohen, Gonzalez-Montesinos, & Castro-Pinero, 2015; Holsgaard Larsen,
62 Caserotti, Puggaard, & Aagaard, 2007; Janot, Beltz, & Dalleck, 2015; Rittweger, Schiessl,
63 Felsenberg, & Runge, 2004), which relies on the ability of the lower limb muscle groups to
64 elevate the body's centre of gravity, and is considered a measure of lower body power
65 (Shetty & Etnyre, 1989). Among athletic populations, there is a strong association between
66 CMJ performance and high-intensity efforts in sports such as sprinting (West et al., 2011;
67 Wisloff, Castagna, Helgerud, Jones, & Hoff, 2004) and weightlifting (Carlock et al., 2004).
68 Furthermore, CMJ performance is used as a screening tool to monitor neuromuscular
69 fatigue (Gathercole, Sporer, Stellingwerff, & Sleivert, 2015), to monitor performance
70 improvements following training interventions (Garcia-Pinillos, Soto-Hermoso, & Latorre-
71 Roman, 2015), and to differentiate between elite and non-elite athletes (Gabbett, 2002).
72 CMJ performance has also been used to assess functional capacity in older adults (Holsgaard
73 Larsen et al., 2007; Rittweger et al., 2004). Given the associations with functional
74 performance in a variety of populations, valid and reliable measures of CMJ which can be
75 used in field or clinical settings are important.

76

77 In general, force platforms are considered the gold-standard instrument for
78 assessment of CMJ performance characteristics (Mauch et al, 2014). However, due to their
79 high cost, their use is frequently limited to research centres, elite sports facilities, or

80 academies and institutes of sport. Coaches and clinicians working in the field seek
81 instruments that provide valid and reliable measure of CMJ performance, without the cost
82 and complexity associated with laboratory- or elite sport-based tools. In response to this
83 need, and with the emergence of novel technologies, a number of portable devices are now
84 available to assess CMJ height including contact mats (Pagaduan & De Blas, 2004),
85 photoelectric cells (Bosquet, Berryman, & Dupuy, 2009), smart phone applications
86 (Balsalobre-Fernández, Glaister, & Lockey, 2015) and accelerometric systems (Casartelli,
87 Muller, & Maffiuletti, 2010). Among these devices, the Myotest (Myotest SA, Sion,
88 Switzerland) (MT) and ChronoJump (Bosco Systems, Madrid, Spain) (CJ) are among the
89 options available to field based practitioners.

90

91 The MT uses an accelerometer which is attached at waist level via a purpose built
92 Velcro belt (Casartelli et al., 2010; Castagna et al., 2013; Choukou, Laffaye, & Tair, 2014).
93 The MT calculates CMJ height based on the acceleration of the centre of mass during the
94 vertical displacement (Castagna et al., 2013). Previous research examining the validity
95 (Casartelli et al., 2010; Choukou et al., 2014) and reliability (Choukou et al., 2014) of the MT
96 has resulted in variable outcomes, dependant on the comparator, and the model of Myotest
97 device. In contrast to the accelerometer-based MT, the CJ system consists of a contact mat
98 and timing device, which calculates CMJ height from flight time, using standard equations
99 (de Blas, Riu, del Amo, & Bálic, 2012; Pagaduan & De Blas, 2004). De Blas and colleagues
100 (2012) describe the development and validity of the CJ to assess flight time, using a
101 fibreglass contact mat. However, like the MT, studies examining the validity of contact mat
102 systems are dependent on the type of mat and comparator device (García-López, Morante,

103 Ogueta-Alday, & Rodríguez-Marroyo, 2013). Data such as these make it difficult to confirm
104 the usefulness of portable devices such as MT and CJ to determine CMJ performance, and
105 subsequently make recommendations to clinicians and coaches.

106

107 One method to directly compare devices with the gold-standard FP, is to perform
108 CMJs on a FP overlaid with a contact mat system, while the performer wears the MJ
109 accelerometer. Such a study would allow direct, simultaneous comparison of both devices
110 with the FP and therefore provide useful information to coaches as clinicians as to the
111 suitability of each device for use in the field. Therefore the aim of the present study was to
112 compare the CMJ height obtained from the MT and CJ compared to a gold-standard force
113 platform in a broader population.

114

115

116 **Methods**

117 ***Subjects***

118 Thirty recreationally active adults from the University community were recruited via
119 face to face contact. For the purpose of the present study, recreationally active was defined
120 as having been engaged in regular sport or recreational activities for a minimum of 12
121 months prior to inclusion in the study. An overview of the study outlining the purpose, and
122 the potential risks and benefits of participation was provided to all subjects. All subjects
123 were screened for injury and health concerns that may have impeded study participation
124 using Stage 1 of the Adult Pre-exercise Screening System (APSS) (ESSA, 2011) prior to
125 participation, and written informed consent was obtained from all subjects. The study was
126 approved by the Institutional Human Research Ethics Review panel prior to the
127 commencement of the study.

128

129 ***Design***

130 A cross sectional, comparative design was used. CMJ performance (jump height) was
131 simultaneously assessed using CJ and MT, with both methods compared to the FP. For the
132 CJ and FP, CMJ performance was determined from flight time using the following equation;
133 $h = t^2 \times 1.22625$ (Bosco, Luhtanen, & Komi, 1983). For the MT, CMJ height was determined
134 using proprietary software. To ensure the generalisability of our findings, a convenience
135 sample from the local University community was used as subjects.

136

137 ***Methodology***

138 Following assessment of body mass and height, subjects completed a standardised
139 warm-up protocol comprising 5-minutes cycling at 50W on a Monark 828e cycle ergometer
140 (Monark Exercise AB, Vansbro, Sweden), followed by 5-minutes of static and dynamic
141 stretching of the quadriceps, hamstrings and gastrocnemius/soleus muscles. Subjects then
142 performed three CMJ attempts, separated by 60 seconds rest, which acted as familiarisation
143 attempts. For each of the three warm up attempts, the intensity increased with each
144 attempt until maximal effort was exerted on the final attempt of the warm-up. For the final
145 warm up, and for each testing attempt, subjects were instructed to stand erect, with the
146 feet placed shoulder width apart. Commencing with the hands on the hips, the subject
147 performed a partial squat to a self-determined depth, followed by a rapid amortisation
148 phase and explosive concentric phase in attempt to maximise vertical displacement of the
149 body. Following the completion of warm up attempts, two maximal effort trials were
150 recorded and the mean of the two trials was used for subsequent analysis. Each attempt
151 was visually inspected by a member of the research team to ensure correct technique and
152 landing position. No repeat attempts were required for any participant.

153

154 Following a further 3-minute rest, subjects performed two maximal effort CMJ
155 attempts, separated by 3-minute of passive (seated) rest. Subjects stood on an AMTI force
156 plate (BP600900-1000, Advanced Mechanical Technology Incorporated, Watertown, MA),
157 interfaced with an AMTI MSA-6 amplifier (Advanced Mechanical Technology Incorporated,
158 Watertown, MA). Data were sampled at 1000Hz, filtered using a 2nd order low pass
159 Butterworth filter with a cut-off frequency of 10Hz, and data were collected for 5 seconds
160 using custom written Labview software (Version 2013, National Instruments, Austin, TX).

161 CMJ height was calculated from flight time using the following equation; $h = t^2 \times 1.22625$
162 (Bosco et al., 1983). This method shows strong correlation with a modified Wingate test
163 ($r=0.87$) and 60m sprint ($r=0.86$). The force plate was zeroed prior to the participant
164 standing on the force plate and flight time was defined as the time the vertical ground
165 reaction force (vGRF) was below 10N (Linthorne, 2001).

166

167 The force plate was overlaid with a Din A2 (420 x 594 mm) sized contact mat (Bosco
168 Systems, Madrid, Spain) connected to a Chronopic 3 timing interface (Bosco Systems,
169 Madrid, Spain). Data were collected using Chronojump software (Version 1.6.1.0; Bosco
170 Systems, Madrid, Spain). For this type of device, the contact mat operates as a simple on/off
171 switch and triggers timing of the duration the switch is in the closed position such as when a
172 participant is standing on the contact mat, or in the open position; for example when a
173 participant is in the air as in the performance of a CMJ. Timing is based on the internal clock
174 of the computer on which the software is installed.

175

176 For each CMJ attempt, subjects also wore a Myotest Pro accelerometer system
177 (Myotest SA, Sion, Switzerland), secured over the subject's right hip using the proprietary
178 elasticized band in accordance with manufacturer's instructions. The Myotest Pro is a small
179 (54.2 x 10.7 x 102.5mm) light weight (59 g) device containing a triaxial accelerometer (± 8 g)
180 which records acceleration at 500 Hz. Prior to use, the Myotest Pro was programmed with the
181 subjects height and weight using Myotest Pro software (Version 1.988, Myotest SA, Sion,
182 Switzerland). For the Myotest Pro, CMJ height was determined using proprietary software.
183 The exact method by which the MT determines CMJ height is unclear, however, Choukou

184 and colleagues (2013) report flight time as the time between maximal vertical velocity and
185 minimal vertical velocity after touchdown, which must in turn be derived from the
186 integration of acceleration data.

187

188 ***Statistical analysis***

189 Descriptive statistics (mean \pm standard deviation (SD)) were used to report subject
190 and jump characteristics. Normality was assessed by Kolmogorov-Smirnov test, and
191 skewness and kurtosis z-scores. Pearson's correlations were used to independently examine
192 the validity of the CJ and MT devices, and interpreted as 0.00-0.19 = very weak, 0.20 – 0.39
193 = weak, 0.40 – 0.59 = moderate, 0.60 – 0.79 = strong, and 0.80 – 1.00 = very strong (Evans,
194 1996). Fisher's r-z transformations were used to examine the significance of any difference
195 between the correlation coefficients. Differences in mean CMJ performance between CJ and
196 FP, and between MT and FP were examined using paired samples t-tests, with Bonferroni
197 adjustments for multiple comparisons. The magnitude of difference between mean jump
198 heights were also assessed using Cohen's d where $d > 0.8$ is a large effect, $d = 0.5 – 0.8$ is a
199 moderate effect; $d = 0.2 – 0.5$ is a small effect; and $d < 0.2$ is a trivial effect (Cohen, 1988).
200 Finally, agreement between CJ and FP, and between MT and FP were examined using Bland-
201 Altman plots, with mean differences (systematic bias) calculated as FP – CJ and FP – MT,
202 respectively. All statistical analyses were performed using Statistical Package for the Social
203 Sciences (SPSS) Version 22 (IBM Corp, Armonk, NY). Bland Altman plots were constructed
204 using Microsoft Excel 2013 (Microsoft Corp, Redmond, WA). Statistical significance (two-
205 tailed) was set at an alpha level of 0.05.

206

207 **Results**

208 Thirty jump heights registered by each device were analysed. Mean jump heights
209 were 20.96 ± 6.88 cm, 26.22 ± 6.96 cm, and 22.15 ± 6.13 cm for the CJ, MT and FP,
210 respectively. Figure 1 shows a strong, statistically significant correlation between jump
211 height derived from the CJ and FP ($r = 0.65$, $p < 0.01$). Paired samples t-test revealed no
212 statistically significant difference between jump height derived from the CJ and FP ($t(29) =$
213 1.19 ; $p > 0.05$; $d = 0.18$, *trivial*). Bland Altman plot depicting limits of agreement between CJ
214 and FP is shown in Figure 2. Compared to FP, CJ underestimates CMJ height by 1.18 ± 5.46
215 cm.

216

217

INSERT FIGURE 1 ABOUT HERE

218

219

INSERT FIGURE 2 ABOUT HERE

220

221 Figure 3 shows a strong, statistically significant correlation between jump height
222 derived from the MT and FP ($r = 0.66$, $p < 0.01$). Paired samples t-test revealed a statistically
223 significant difference between jump height derived from the MT and FP ($t(29) = 4.09$; $p <$
224 0.001 ; $d = 0.64$, *moderate*). Bland Altman plot depicting limits of agreement between MT
225 and FP is shown in Figure 4. Compared to FP, MT overestimates CMJ height by 4.07 ± 5.45
226 cm. Fisher's r-z transformation revealed no statistically significant difference between the
227 correlation between CJ and FP, and between MT and FP ($z = -0.06$, $p > 0.05$)

228

229

INSERT FIGURE 3 ABOUT HERE

230

231

INSERT FIGURE 4 ABOUT HERE

232

233

234 **Discussion**

235 The present study examined the validity of the ChronoJump contact mat and
236 Myotest accelerometer system compared to a laboratory-based force platform for
237 measuring CMJ height, in recreationally active males and females. The main findings of this
238 study were that: (1) CMJ height derived from both CJ and MT was strongly and significantly
239 correlated with FP-derived measures; (2) CJ derived measures of CMJ were not significantly
240 different to FP-derived measures, but MT-derived measures were; and (3) MT overestimates
241 CMJ height, whilst the CJ marginally underestimates CMJ height, compared to the FP.

242

243 The findings from the present study are in agreement with the those reported by
244 Castagna and colleagues (Castagna et al., 2013) who found the difference between FP and
245 an optical-based measure of flight time, to be small ($d= 0.09$), while differences between the
246 MT and FP were moderate ($d=0.54$). Interestingly the present study, and that of Castagna
247 and colleagues (2013), observed both a moderate effect size and larger systematic bias
248 when using the MT, than a contact mat or optical timing system to assess CMJ height
249 against a force platform. From a practical point of view, these results suggest the two
250 systems provide different results, with the CJ measures of CMJ height closer to gold-
251 standard values, and subsequently more accurate. In contrast, the MT appears to be
252 affected by a greater systematic bias, which leads to an overestimation of CMJ height by
253 approximately 4 cm.

254

255 In the present study, the Bland Altman plot show a systematic bias of -1.18 ± 6.87 cm
256 in CMJ height between the CJ and FP. This data suggest good levels of agreement, which
257 supports the validity of the CJ in measuring CMJ height when compared to the gold-
258 standard. Previous studies comparing CMJ height measures using differing contact mats
259 with force platforms (Enoksen, Tonnessen, & Shalfawi, 2009; García-López et al., 2013;
260 Kenny & Comyns, 2012) and a 3-dimensional camera system (Leard et al., 2007) report
261 mean differences ranging from -1.3 cm to 2.8 cm. The results of the present study compare
262 favourably with Garcia-Lopez and colleagues (2013) who reported CMJ height was
263 underestimated when using a contact mat compared to a force platform. In contrast, our
264 results are in disagreement with the findings of Enoksen and colleagues (2009) who
265 reported CMJ height was overestimated when comparing a contact mat with a force
266 platform. As Buckthorpe and colleagues (2012) noted, the likely reason for discrepancies in
267 CMJ height between contact mats and force platforms, is the methodology underpinning
268 flight time and initial velocity measurement. When performing a CMJ on a contact mat, the
269 timer starts when the subject leaves the ground, which may fail to capture the initial rise of
270 the centre of mass before take-off. Furthermore, the flight time method assumes the take-
271 off and landing positions will be identical, ensuring the duration of the ascending and
272 descending phases of flight time are the same (Buckthorpe et al., 2012). In the present study,
273 these discrepancies are evident by the presence of outliers. For example, Figure 1 shows
274 one data point where CMJ height determined using the CJ was approximately 15cm, yet was
275 approximately 34cm based on FP data. Such discrepancies may result from the use of a 10N
276 threshold to determine contact times on the FP, the use of poor landing technique, or lack
277 of reliability in CMJ performance. Taken together, these data may further explain the small

278 systematic bias observed with the CJ and FP measures of CMJ height observed in the current
279 study.

280

281 Similar to the CJ, the present study showed a strong significant correlation between
282 MT and FP. However, mean jump heights were statistically significantly different. As
283 observed in Figure 4, MT overestimated CMJ by 4.07 ± 6.96 cm. Previous studies have
284 compared CMJ height assessed via MT, with both portable (Choukou et al., 2014; Mauch et
285 al., 2014) and in-built force platforms (Monnet, Decatoire, & Lacouture, 2014), reporting
286 mean differences between -1.09 to 4.8 cm. Similar to our findings, Monnet and colleagues
287 (2014) reported a mean difference of 4.8 ± 6.90 cm when comparing CMJ height between
288 the Myotest and a FP. The overestimation of CMJ height by the MT may be related to errors
289 in flight time estimation (Choukou et al., 2014). Choukou and colleagues (2013) report that
290 flight time is the time between maximal vertical velocity and minimal vertical velocity after
291 touchdown. This equation cannot be verified from the device manual and to the best of our
292 knowledge, no published study has fully described the known method for deriving flight
293 time from accelometric data collected using the Myotest Pro device employed in the
294 present study. Additionally, velocity is obtained from the integration of acceleration data
295 and this mathematical manipulation may introduce errors magnified by downstream
296 calculations, or as a result of variations in CMJ technique.

297

298 Alternatively, rotational effects on the MT, due to its placement on the hip may
299 account for this overestimation, since any rotation of the pelvis during the CMJ will affect
300 tracking of the body's centre of mass and thus its measurement of CMJ height (Mauch et al.,

301 2014). Interestingly, Monnet and colleagues (2014) demonstrated a reduction in CMJ height
302 bias from $4.8 \pm 9.4\text{cm}$ to $-1.3 \pm 9.2\text{cm}$ after defining a new threshold to detect take-off and
303 landing times. Thus, in the present study it is unclear if the measurement itself or the
304 applied algorithm is producing the discrepancy in CMJ height. Nonetheless, this is a
305 limitation that practitioners using the device need be aware of.

306

307 Another potential explanation for the finding of the present study may be the degree
308 of sample homogeneity. The present study did not collect training age history as a
309 demographic variable; rather, engaged recreationally active participants, operationalised as
310 having been engaged in regular sport or recreational activities for a minimum of 12 months.
311 Training history has recently been shown to affect the reliability of CMJ performance.
312 Lombard and colleagues (2017) reported that reliability was greater for participants more
313 accustomed to strength training. Therefore repeat testing is capable of detecting small
314 differences in performance which may be clinically or functionally meaningful. Participants
315 in the current study met the definition of 'trained' used by Lombard and colleagues (2017)
316 based on training duration (>12 months), but not on training type (strength training
317 specifically). Therefore replication of the present study in a more homogeneous athletic
318 population may be warranted.

319

320 **Practical applications**

321 The present study compared CMJ performance using field measures (CJ and MT) with
322 laboratory-based measures (FP) in a convenience sample of recreationally active University
323 students. Results showed that the CJ is a valid, portable device to assess CMJ height.

324 Moreover, the differences between the CJ and FP were trivial considering the practical
325 significance. In contrast, whilst the MT also demonstrates good validity, this device showed
326 a moderate difference in CMJ height when compared to the FP. Despite these important
327 findings, the confidence intervals are wide for both the CJ (12.10 – -9.73cm), and the MT
328 (6.83 – -14.93 cm). Therefore the devices may lack the sensitivity to detect small changes in
329 performance. Nonetheless, the use of the CJ in the present study offered several advantages
330 for the assessment of CMJ height in the field, compared to the MT. These include lower
331 purchase costs, reduced time to complete the test, and more rapid reporting of results. In
332 addition, the software is free and open source, runs on multiple operating systems, and is
333 available in multiple languages. Whilst the MT offers the advantage of being able to be used
334 on a wider variety of surfaces, the significant overestimates of CMJ height, and the use of a
335 Velcro belt to secure the MT unit to the subjects' hip reduces its potential usefulness.
336 Collectively, this suggests the use of the MT for the rapid field evaluation of CMJ height may
337 be limited compared to CJ. The results of the present study may have direct implications for
338 strength and conditioning professionals, sport scientists and coaches who do not have direct
339 access to performance laboratories.

340

341 **Conclusions**

342 Based on correlation coefficients, both the CJ and MT systems are valid instruments
343 for the field assessment of CMJ height. However, CMJ height assessed using the MT is
344 significantly different from that recorded using the FP. Additionally, the MT demonstrates
345 greater systematic bias compared to the CJ. Because of these differences in measurement
346 outcomes, coaches and clinicians should use caution when interpreting and comparing data

347 from these devices. Users should be aware of systematic bias in both devices. To minimise
348 bias and improve reliability, consistent measurement conditions including the use of the
349 same device should be employed for all testing occasions.

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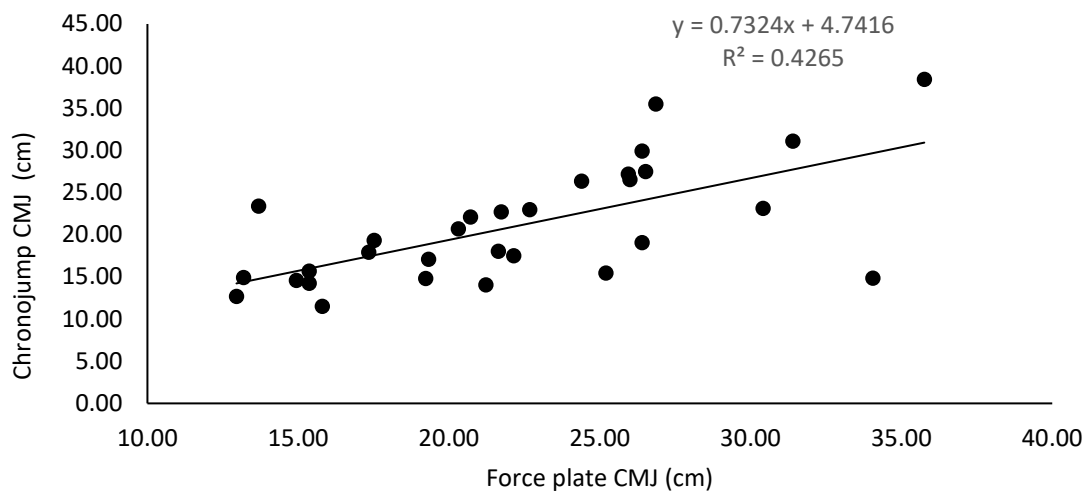
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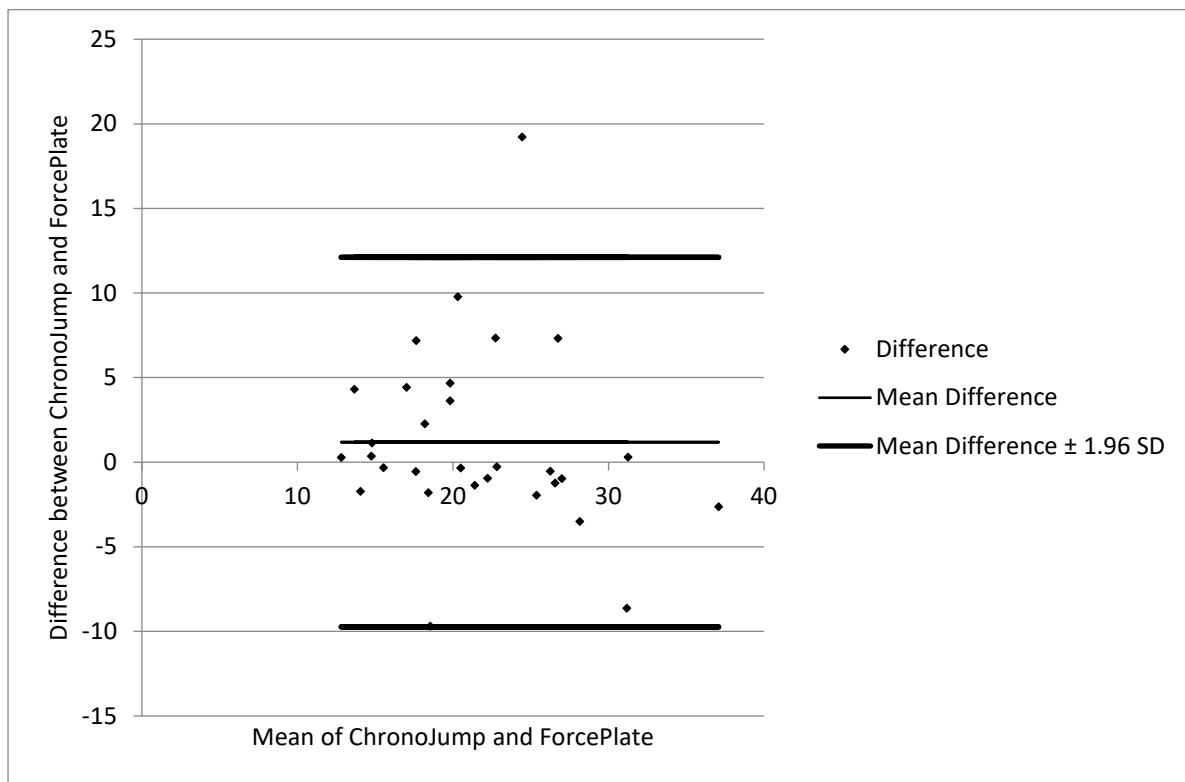
458 Figure 1. Correlation between CMJ jump height measured with CJ and FP



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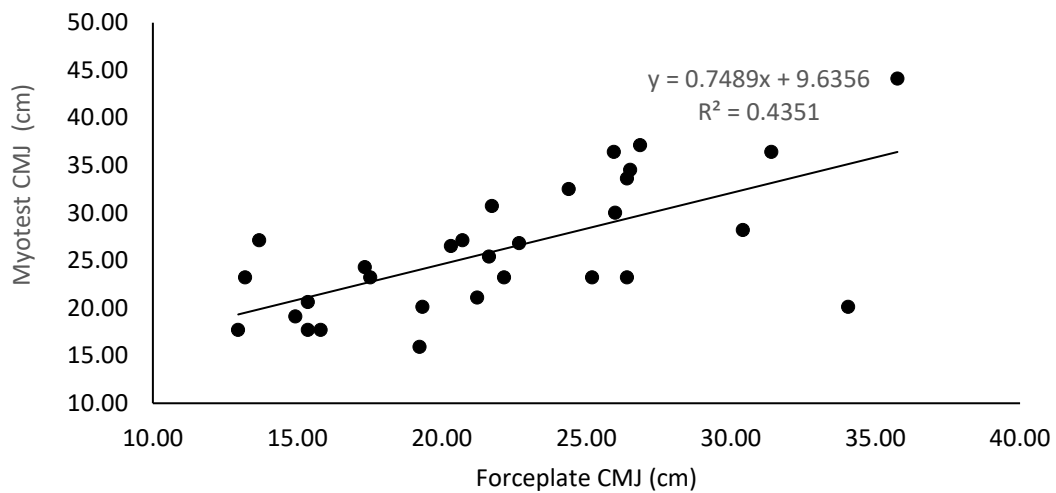
461 Figure 2. Bland and Altman Plot (n=30) comparing CJ and FP. Mean difference = 1.18 ± 5.46
462 cm, 95% CI = 12.10 – -9.73 cm



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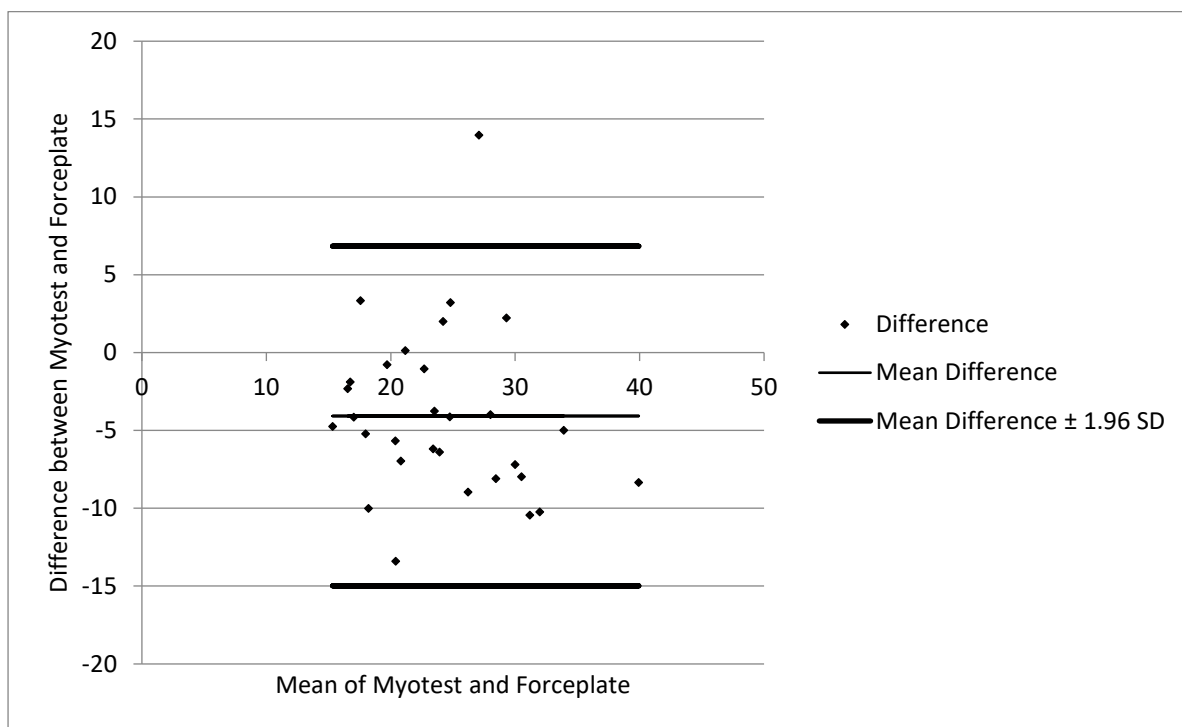
465 Figure 3. Correlation between CMJ jump height measured with MT and FP



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468 Figure 4. Bland and Altman Plot (n=30) comparing MT and FP. Mean difference = $-4.07 \pm$
469 5.45cm , 95% CI = $6.83 - -14.93 \text{ cm}$



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