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1 **Comparison of methods of calculating dynamic strength index**

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11 **Original Investigation**

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Comparison of methods of calculating dynamic strength index

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Abstract

Purpose: To determine the reliability and variability of dynamic strength index (DSI) calculated from squat jump (SJ) (DSI-SJ) versus countermovement jump (CMJ) (DSI-CMJ) peak force (PF) and to compare DSI values between methods. **Methods:** Male youth soccer and rugby league players ($n = 27$; age = 17.2 ± 0.7 years; height = 173.9 ± 5.7 cm; body mass = 71.1 ± 7.2 kg) performed 3 trials of the SJ, CMJ and isometric mid-thigh pull (IMTP), on two separate days. DSI was calculated by dividing the PF during each jump by the IMTP PF. **Results:** DSI-SJ exhibited moderate (intraclass correlation coefficient (ICC) = 0.419) within-session reliability and high variability (percentage coefficient of variation (%CV) = 15.91) during session one; however, this improved noticeably during session two (ICC = 0.948; %CV = 4.03). Contrastingly, DSI-CMJ showed nearly perfect within-session reliability (ICC = 0.920-0.952) and low variability (%CV = 3.80-4.57) for both sessions. Moreover, DSI-SJ values demonstrated a small yet significant increase between sessions ($P = 0.01$, $d = 0.37$), whereas only a trivial and non-significant increase was observed for DSI-CMJ between sessions ($P = 0.796$ $d = 0.07$). Between-session reliability was very high for the DSI-SJ (ICC = 0.741) and nearly perfect for the DSI-CMJ (ICC = 0.924). There was no significant or meaningful difference ($P = 0.261$; $d = 0.12$) between DSI-SJ (0.82 ± 0.18) and DSI-CMJ (0.84 ± 0.15). **Conclusions:** Practitioners should use DSI-CMJ as it is a more reliable measure than DSI-SJ, although it produces similar ratios.

73 Introduction

74 Strength has been shown to underpin performance in numerous athletic tasks,¹ including
75 sprint,²⁻⁴ jump^{5, 6} and change of direction performance.⁶⁻⁸ However, strength is commonly
76 assessed using a variety of methods, including one repetition maximum (1RM) testing, during
77 different compound exercises,^{2-4, 6} and peak force (PF) assessed during the isometric mid-thigh
78 pull (IMTP)^{5, 9, 10} and the isometric squat.¹¹

79 While 1RM assessments are easy to conduct, can be incorporated within scheduled training
80 sessions, demonstrate high reliability^{12, 13} and are regularly used to prescribe training intensity,
81 such testing can be fatiguing and only provide a maximal load lifted. In contrast, minimal
82 fatigue is likely to result from performance of the IMTP, and additional information regarding
83 rate of force development (RFD)^{14, 15}, impulse, and force produced across specific epochs (e.g.
84 0-100, 0-150, 0-200 ms) can be determined¹⁵⁻¹⁷. Such information may provide the practitioner
85 with greater information regarding the athlete's ability to express not only maximal force, but
86 their ability to rapidly produce force. It is worth noting however, that the reliability of the RFD
87 calculation during the IMTP has been questioned, with peak RFD over short epochs (2-50 ms)
88 being suggested to be the most reliable of the available measures.¹⁴

89 To provide greater insight into an athlete's training status, the ratio of ballistic PF, produced
90 during a squat jump (SJ) or a countermovement jump (CMJ), and PF during the IMTP has been
91 discussed within the literature.^{9, 10, 18-21} This ratio is commonly referred to as the dynamic
92 strength index (DSI) or the dynamic strength deficit and has been reported to be highly reliable
93 (intraclass correlation coefficient (ICC) 0.952-0.987) with low variability (2.01-4.60%
94 coefficient of variation percentage (CV%)).^{19, 22} Recommendations for interpreting the ratio
95 suggest focusing on ballistic force production when the ratio is low (< 0.60) and maximal
96 strength development when the ratio is high (> 0.80).¹⁹ However, it is important to note that in
97 athletes with low relative strength, developing relative strength may be more advantageous
98 than focussing on achieving a specific ratio.^{23, 24}

99 As the calculation of DSI using both PF attained during the SJ and CMJ has been reported
100 within the literature, it is important to determine whether the differences in these methods
101 affects not only the reliability and variability of the measures, but also the resultant DSI ratios.
102 Due to the CMJ incorporating the stretch-shortening cycle (SSC), it is likely that the PF will
103 be higher when compared to the PF attained during the SJ.^{25, 26} Additionally, it is not clear
104 from the studies that have used the CMJ, if the PF was obtained during the braking or
105 propulsive phase which may affect the resultant PF,^{9, 10, 20, 21} as the phase in which PF occurs
106 differs between individuals. The aim of this study, therefore, was to determine the reliability
107 and variability of DSI ratios when calculated based on PF attained during the SJ (DSI-SJ) and
108 CMJ (DSI-CMJ) and to compare the resultant DSI values between methods. It was
109 hypothesised that both methods would be reliable, both within- and between sessions, with
110 greater values derived from DSI-CMJ due to the higher PF compared to the DSI-SJ calculation,
111 due to the use of the SSC during the CMJ.

112

113

114 **Methods**

115 **Subjects**

116 Male professional youth soccer and rugby league players ($n = 27$; age = 17.2 ± 0.7 years; height
117 = 173.9 ± 5.7 cm; body mass = 71.1 ± 7.2 kg) participated in this study. All participants
118 provided written informed consent, with consent from the parent or guardian of all subject
119 under the age of 18 years. The study procedures were approved by the University Institutional
120 Review Board, and procedures conformed to the Declaration of Helsinki.

121

122 **Procedures**

123 To determine between session reliability, participants were assessed on two separate occasions,
124 at the same time of day, 7 days apart. Testing was conducted within the first 4 weeks of the
125 season, during which time all participants were in full training comprising all the elements of
126 performance including four sport-specific skill based training sessions, plus two lower body
127 resistance training sessions each week. At the time of testing, participants had completed a 4-
128 week strength mesocycle and were in the middle of a 4-week power mesocycle.

129 All athletes rested the day before testing and were asked to attend testing in a fed and hydrated
130 state, similar to their normal practices before training. On arrival, all participants had their
131 height (Stadiometer; Seca, Birmingham, United Kingdom) and body mass assessed (Seca
132 Digital Scales, Model 707), measured to the nearest 0.1 kg and 0.1 cm, respectively. After
133 performing a standardized dynamic warm up, which they were familiar with from all previous
134 off-field training sessions, they performed three maximal effort SJ and CMJ trials, followed by
135 three IMTPs, with five minutes of rest between each test.

136 Data from the second day of testing was used to compare between DSI-SJ and DSI-CMJ and
137 to determine any relationships between the two methods.

138

139 **Jump Testing**

140 Both the SJ and CMJ trials were performed with the subjects standing on a force platform (type:
141 9286AA, dimensions 600 mm x 400 mm, Kistler Instruments Inc., Amherst, NY, USA)
142 sampling at 1000 Hz, interfaced with laptop computer running Bioware software (version 5.11,
143 Kistler Instruments Inc., Amherst, NY, USA). Subjects were instructed to stand still for the
144 initial one second of the data collection period (known as the silent period immediately prior
145 to performing the jumps)^{27, 28} to allow for the subsequent determination of body weight. The
146 raw, unfiltered, vertical force-time data for each jump trial were exported as text files and
147 analysed, in line with previous recommendations to minimise sources of error,²⁹ using a
148 customised Microsoft Excel spreadsheet (version 2016, Microsoft Corp., Redmond, WA,
149 USA).

150 All jumps were performed whilst the subjects kept their hands on their hips, with any jumps
151 that were inadvertently performed with the inclusion of arm swing omitted and additional trials
152 performed after one minute of rest. For the SJ, subjects were instructed to squat down to a self-

153 selected depth (approximately 90°), pause for a count of three and then jump as fast and as high
154 as possible, without performing any preparatory countermovement. Resultant force-time data
155 was visually inspected to determine if any countermovement had been performed, and if it had,
156 subjects repeated the trial after one minute of rest. Subsequent analysis of the SJ force-time
157 data revealed that no trial exceeded the threshold used to determine a countermovement (five
158 times the standard deviation of body weight, as derived during the silent period),^{27, 30} as
159 described below. For the CMJ subjects were instructed to aim to jump as high as possible,
160 performing a rapid dip, to a self-selected depth, which they believed would achieve their
161 greatest jump height. To aid the standardisation of instructions and procedures all, assessments
162 were performed by the same experienced researcher.

163 The start of the jumps were identified in line with current recommendations where the onset of
164 movement for each jump trial was considered to have occurred 30 milliseconds prior to the
165 instant when vertical force had reduced (CMJ) or increased (SJ) by five times the standard
166 deviation of body weight, as derived during the silent period.^{27, 30} The interpretation of the CMJ
167 force-time curves attained in this study is in line with recent research.³⁰ Instantaneous centre
168 of mass (COM) velocity was calculated by dividing vertical force (excluding body weight) by
169 body mass and then integrating the product using the trapezoid rule. The concentric phase of
170 the CMJ and SJ was then defined as occurring between the instant at which COM velocity
171 exceeded 0.01 m·s⁻¹ and take-off.³⁰ The instant of take-off was defined as the instant in time
172 when vertical force was less than five times the standard deviation of the flight force following
173 the onset of movement.²⁷ It was important to clearly identify the concentric peak force
174 (propulsive phase) during the CMJ rather than the eccentric peak force (braking phase) (Figure
175 1), to ensure that this is comparable with the SJ which has no eccentric phase. Concentric PF
176 was defined as the maximum value attained during the propulsion phase of the jumps. Jump
177 height was derived from vertical velocity at take-off with take-off.^{28, 30}

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179

180 [***Insert figure 1 here***]

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184 **Isometric Mid-Thigh Pull Testing**

185 The IMTP was performed using a portable force platform (type: 9286AA, dimensions 600 mm
186 x 400 mm, Kistler Instruments Inc., Amherst, NY, USA) sampling at 1000 Hz, interfaced with
187 laptop computer running Bioware software (version 5.11, Kistler Instruments Inc., Amherst,
188 NY, USA). Raw force-time was subsequently exported and analysed in a custom-made
189 Microsoft Excel spreadsheet. Subjects adopted a posture which replicated the position at which
190 they would start the second pull phase of the clean, with their knee and hip angles within 140-
191 150°, in line with previous research.^{31, 32} An immovable, collarless cold rolled steel bar was
192 positioned around mid-thigh, just below the crease of the hip, using a portable IMTP rig
193 (Fitness Technology, Adelaide, Australia). Once the bar height was established, the athletes
194 stood on the force platform, and their hands were strapped to the bar using standard lifting
195 straps. The height of the bar and the resultant joint angles were replicated between trials and
196 between testing sessions.

197 Each athlete performed two warm-up pulls, one at 50% and one at 75% of the athlete's
198 perceived maximum effort, separated by one minute of rest. Once body position was stable
199 (verified by visual inspection of the force trace), the subject was given a countdown of "3, 2,
200 1, Pull." Minimal pretension was allowed to ensure that there was no slack in the subject's
201 body or IMTP rig before initiation of the pull. Athletes performed three maximal IMTP, with
202 the instruction to pull against the bar with maximal effort pulling as fast and hard as possible,
203 and push the feet down into the force platform. Each maximal IMTP trial was performed for
204 five seconds, and all athletes were given strong verbal encouragement during each trial. Two
205 minutes of rest was given between the maximal effort pulls. Trials were repeated if the PF
206 values varied by >250 N in line with previous research.^{16, 17, 31, 32} The maximum force recorded
207 from the force-time curve during the five-second IMTP trial was reported as the PF. Each of
208 the 3 trials was used to determine within session reliability, with the mean of the best two trials,
209 based on PF, used to compare between sessions, in line with previous research.^{31, 32}

210 The DSI was calculated by dividing jump PF by IMTP PF, with DSI-SJ using PF from the SJ
211 and DSI-CMJ using PF from the CMJ.

212

213 **Statistical Analyses**

214 Within- and between-session reliability of dependent variables was examined using the ICC,
215 and typical error of measurement (TE) expressed as a CV%. A CV of $\leq 10\%$ was considered
216 to be reflective of acceptable variability.³³ Specifically, a two-way random effects model ICC
217 was used to determine within- and between-session reliability (internal consistency), with
218 paired samples t-tests and Cohen's *d* effect sizes used to determine if any differences occurred
219 between days, between the two methods of calculating DSI (DSI-SJ and DSI-CMJ) and
220 between PF achieved during the SJ and CMJ. Finally, Pearson's correlation was performed to
221 determine the relationship between both methods of assessing DSI, based on the resultant
222 values from the second day of testing, due to the higher reliability and lower variability
223 observed.

224 To assess the magnitude of the ICC, the values were interpreted as low (<0.30), moderate (0.30-
225 0.49), high (0.50-0.69), very high (0.70-0.89), nearly perfect (0.90-0.99), and perfect (1.0),
226 respectively.³⁴ The magnitude of differences, as determined using Cohen's *d*, between sessions
227 were classified as trivial (≤ 0.19), small (0.20 – 0.59), moderate (0.60 – 1.19), large (1.20 –
228 1.99), and very large (2.0 – 4.0).³⁵

229 Normality of data was assessed by Shapiro–Wilk statistic and Q-Q plot analysis. Relationships
230 between variables were determined using Pearson's product-moment correlation coefficients.
231 Correlations were evaluated as follows: small (0.10 – 0.29), moderate (0.30 – 0.49), large (0.50
232 – 0.69), very large (0.70 – 0.89), nearly perfect (0.90 – 0.99), and perfect (1.0).³⁵ Statistical
233 analyses were conducted using SPSS software (version 23.0; SPSS, Inc.) with an alpha level
234 of $P \leq 0.05$.

235

236 **Results**

237 DSI-SJ showed poor to moderate within-session reliability and high variability during session
238 one; however, this improved during session two resulting in nearly perfect within-session

239 reliability and reduced variability (Table 1). In contrast, DSI-CMJ showed nearly perfect
240 within-session reliability and low variability for both testing sessions. Moreover, DSI-SJ
241 demonstrated a small yet significant increase between sessions, whereas there was only a trivial
242 and non-significant increase in DSI-CMJ between sessions (Table 1). Between-session
243 reliability was very high for the DSI-SJ (ICC = 0.741) and nearly perfect for the DSI-CMJ
244 (ICC = 0.924).

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[***Insert Table 1 here***]

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250 There was no significant or meaningful difference ($P = 0.261$; $d = 0.12$) between DSI-SJ (0.82
251 ± 0.18) and DSI-CMJ (0.84 ± 0.15) (Figure 2), with a trivial and non-significant difference (P
252 $= 0.272$; $d = 0.19$) in PF between the SJ (1789 ± 350 N) and the CMJ (1854 ± 345 N). The
253 results of Pearson's correlation analysis showed a very large positive relationship ($r = 0.797$;
254 $R^2 = 0.635$) between DSI-SJ and DSI-CMJ (Figure 3).

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[***Insert figure 2 here***]

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[***Insert figure 3 here***]

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267 Discussion

268 This study examined the reliability and variability of DSI-SJ and DSI-CMJ and compared the
269 resultant DSI values between methods. The DSI-SJ demonstrated improved reliability and
270 reduced variability between sessions, with a small and significant increase in values between
271 sessions. In contrast, there was no notable change in reliability and variability, or any
272 meaningful or significant change in DSI-CMJ between sessions (Table 1), highlighting that
273 DSI-CMJ is a more stable method of assessing DSI compared to DSI-SJ. In contrast to our
274 hypotheses, there was no meaningful or significant difference between DSI-SJ and DSI-CMJ,
275 with strong associations between DSI values determined using either method.

276 The greater variability and lower reliability observed for DSI-SJ is likely due to the difficulties
277 associated with subjects consistently performing the SJ, without any countermovement, while
278 attempting to jump as high as possible from a static squat position. It is therefore plausible that
279 greater familiarisation with the SJ is required, which is likely to improve the reliability and
280 reduce the variability of the performances, as observed during the second day of testing. In line
281 with previous observations,^{25,26} the inclusion of the countermovement during the CMJ resulted
282 in a higher PF (3.6%) than that observed during the SJ, although this difference was trivial and

283 non-significant. This non-significant difference in PF between the CMJ and SJ explain the
284 trivial and non-significant differences in DSI-CMJ and DSI-SJ. In contrast, and as expected, a
285 moderate and significantly greater jump height (12%) was achieved during the CMJ compared
286 to the SJ, most likely due to the utilisation of the SSC resulting in increased force from the
287 neurological potentiation and contribution from the elastic components.

288 The reliability and variability values in the current study are in line with those previously
289 reported,^{19, 22} although the reliability of the DSI-SJ from session one shows notably lower
290 reliability and much higher variability than presented in previous research.^{19, 22} This higher
291 variability in the DSI-SJ, during session one, with an increased reliability and reduced
292 variability during session two suggests a potential learning effect during the SJ. However,
293 further research is needed to examine potential learning effects on SJ performance.

294 Given that CMJ testing is one of the most commonly used tools in athlete monitoring, it may
295 be preferable to use DSI-CMJ ratios compared to DSI-SJ. In addition to DSI, the CMJ offers
296 the opportunity to assess a variety of other performance characteristics that may not be possible
297 with the SJ, namely the reactive strength index-modified.³⁶ Measuring both DSI and reactive
298 strength index-modified will allow practitioners to assess both isometric and dynamic force
299 production as well as the ability to utilise the SSC, respectively.³⁷ Such an approach may
300 provide a more comprehensive assessment of an athlete's force production qualities.

301 The use of only three trials for each of the jumps, especially during the initial testing session,
302 is a potential limitation of this investigation, due to the low reliability and high variability
303 observed during the SJ. While such an approach is ecologically valid, and in line with applied
304 practice, it is suggested that future research consider applying a similar approach to that
305 commonly used with the IMTP,^{16, 17, 31, 32} where a specific force threshold (<250 N) is used to
306 determine if trials are acceptable. Additionally, future research should adopt a precise method
307 to determine and standardise the squat depth during the performance of the SJ, which may aid
308 in improving reliability and reducing variability of such performance.

309

310 **Practical Applications**

311 The results of the current study provide options to practitioners who would like to use DSI as
312 an athlete monitoring tool. Both DSI-CMJ and DSI-SJ are reliable measures that give
313 practitioners information regarding the ability of an athlete to produce maximal force during
314 isometric and dynamic tasks. However, DSI-CMJ may provide a more consistent measurement
315 as compared to DSI-SJ due to potential learning effects. Moreover, utilising a CMJ as opposed
316 to a SJ may allow for the assessment of other force production characteristics.

317 Based on previous recommendations,¹⁹ it would appear that the athletes in the current study,
318 on average, should focus on developing greater levels of muscular strength. However, it is
319 important to note that training recommendations should be made on an individual basis. In
320 addition, practitioners should be aware that while DSI ratios may help guide training decisions,
321 a paucity of research has been completed on the long-term monitoring of DSI during lower and
322 upper body tasks. Thus, further research is needed that focuses on how specific types of training
323 affect DSI ratios and how DSI ratios relate to other sport performance characteristics.

324

325 **Conclusions**

326 Based on the results of the current study it is suggested that DSI ratios are calculated based on
327 PF during the propulsion phase of the CMJ, as this is more reliable and less variable compared
328 to PF during the SJ. In addition, it is also easier to standardise performance of the CMJ
329 compared to ensuring that athletes do not initiate the SJ with any form of countermovement.

330

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444 Table and Figure Legends

445

446 Figure 1: Illustration of the identification of the specific phases of the CMJ. The **dark line**
447 represents force, while the **grey line** represents velocity of the centre of mass

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449 Figure 2: Comparison of DSI calculated from SJ and CMJ peak force

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451 Figure 3: Relationship between DSI calculated from SJ and CMJ peak force

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453 Table 1: Descriptive statistics (mean \pm standard deviation), within- and between-session
454 reliability (ICC) and variability (CV%) of DSI calculated from peak force during the SJ and
455 CMJ

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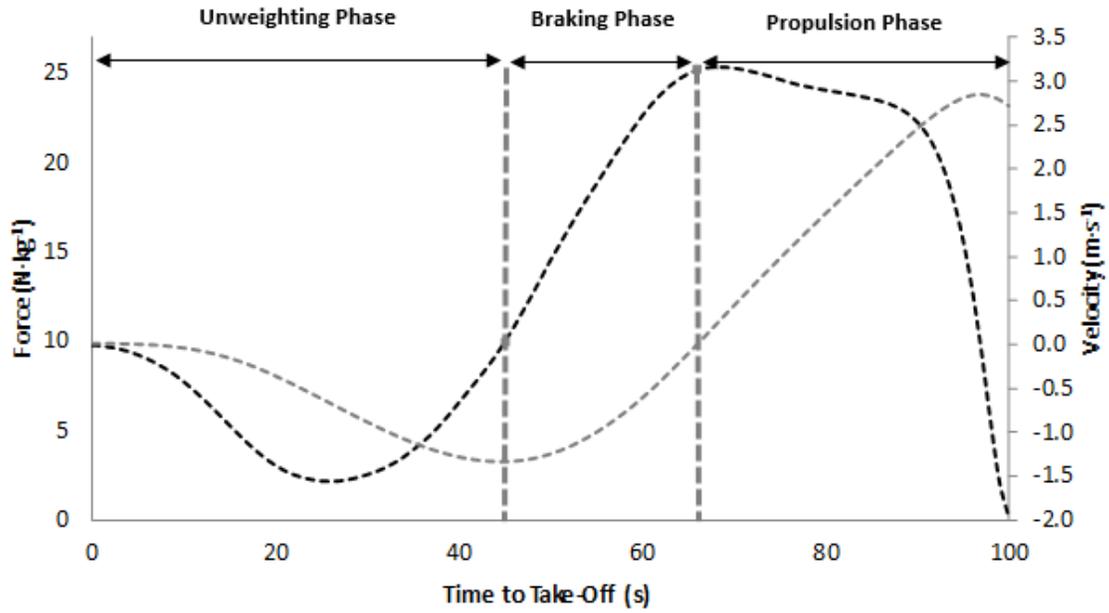
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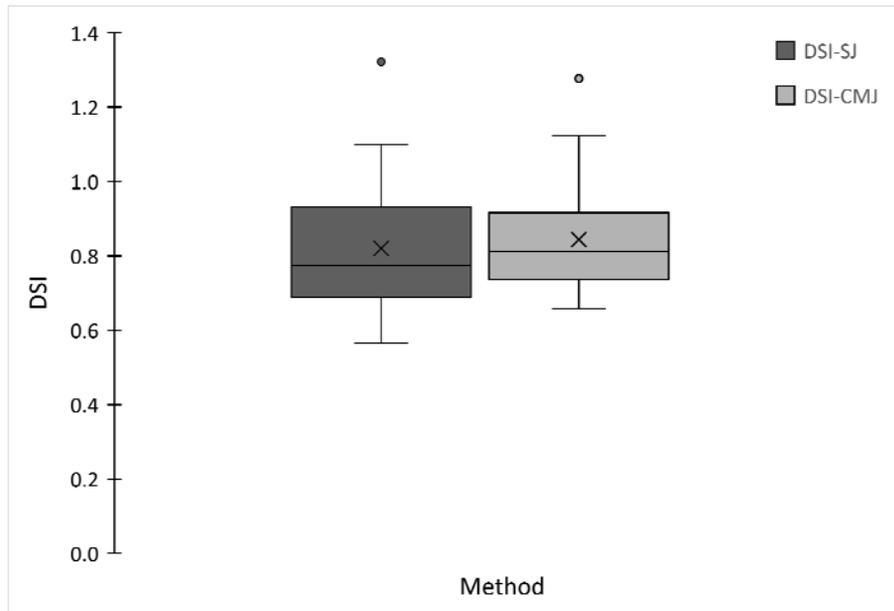


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470 Figure 1: Illustration of the identification of the specific phases of the CMJ. The dark line
 471 represents force, while the grey line represents velocity of the centre of mass

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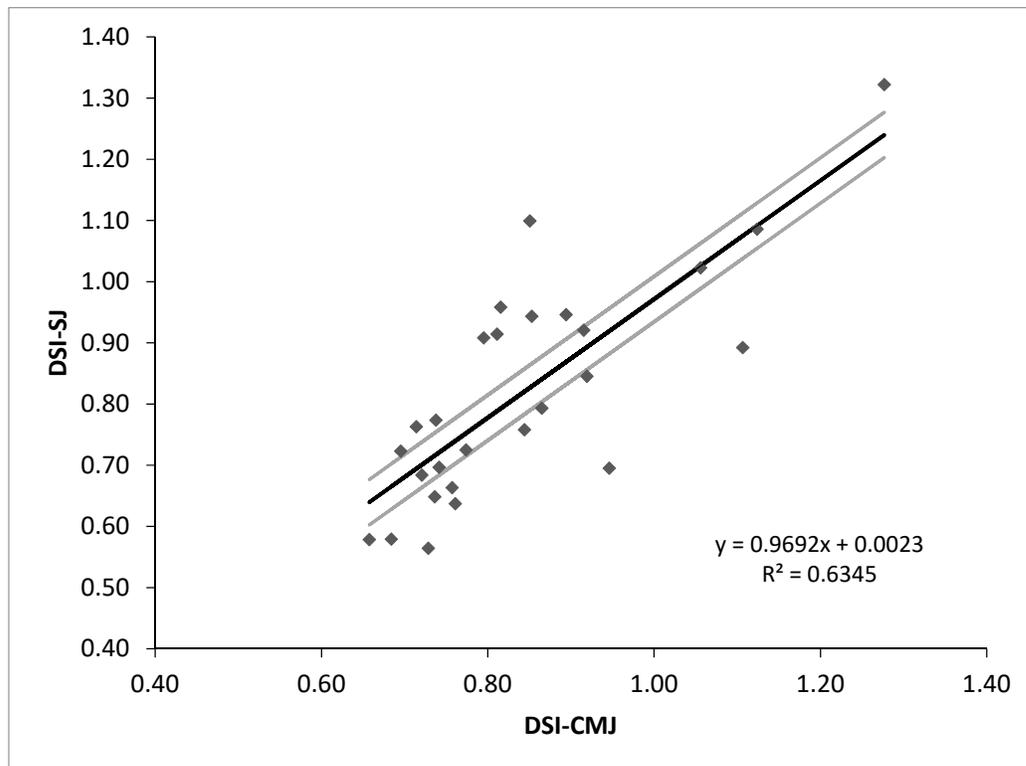
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476 Figure 2: Comparison of DSI calculated from SJ and CMJ peak force

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480 Figure 3: Relationship between DSI calculated from SJ and CMJ peak force (Grey lines depict upper
481 and lower 95% confidence limits)