

Ruggiero, Luca, Dewhurst, Susan and Bampouras, Theodoros (2016) Validity and reliability of two field-based leg stiffness devices: implications for practical use. *Journal of Applied Biomechanics*, 32 (4). pp. 415-419.

Downloaded from: <http://insight.cumbria.ac.uk/id/eprint/2063/>

Usage of any items from the University of Cumbria's institutional repository 'Insight' must conform to the following fair usage guidelines.

Any item and its associated metadata held in the University of Cumbria's institutional repository Insight (unless stated otherwise on the metadata record) may be copied, displayed or performed, and stored in line with the JISC fair dealing guidelines (available [here](#)) for educational and not-for-profit activities

provided that

- the authors, title and full bibliographic details of the item are cited clearly when any part of the work is referred to verbally or in the written form
 - a hyperlink/URL to the original Insight record of that item is included in any citations of the work
- the content is not changed in any way
- all files required for usage of the item are kept together with the main item file.

You may not

- sell any part of an item
- refer to any part of an item without citation
- amend any item or contextualise it in a way that will impugn the creator's reputation
- remove or alter the copyright statement on an item.

The full policy can be found [here](#).

Alternatively contact the University of Cumbria Repository Editor by emailing insight@cumbria.ac.uk.

1 The manuscript below is the post-refereeing version which has been accepted for publication in the
2 Journal of Applied Biomechanics (<http://journals.humankinetics.com/jab>)

3 **October 31, 2015**

4

5 **Validity and reliability of two field-based leg stiffness devices: implications for**
6 **practical use**

7

8 Luca Ruggiero,^{1,2} Susan Dewhurst,¹ Theodoros M. Bampouras¹

9

10 ¹Department of Medical and Sport Sciences, University of Cumbria, Lancaster,
11 LA1 3JD, United Kingdom; ²School of Health and Exercise Sciences, University of
12 British Columbia, Kelowna, British Columbia, Canada.

13

14 **Funding:** *No external funding were received.*

15 **Conflict of Interest Disclosure:** *The authors have no conflict of interest to disclose.*

16 **Correspondence Address:** *Theodoros M. Bampouras, University of Cumbria, Department of*
17 *Medical and Sport Sciences, Human Performance Laboratory, Bowerham Road, Lancaster LA1*
18 *3JD, United Kingdom. Email: theodoros.bampouras@cumbria.ac.uk, Tel. No.: +44 1524 590837.*

19 **Running Head:** *Field-based leg stiffness measurement.*

20 **Abstract**

21 Leg stiffness is an important performance determinant in several sporting activities. This study
22 evaluated the criterion-related validity and reliability of two field-based leg stiffness devices,
23 Optojump Next® and Myotest Pro® in different testing approaches. Thirty-four males
24 performed, on two separate sessions, three trials of 7 maximal hops, synchronously recorded
25 from a force platform (FP), Optojump and Myotest. Validity (Pearson's correlation coefficient, r ;
26 relative mean bias; 95% limits of agreement, 95%LoA) and reliability (coefficient of variation,
27 CV; intraclass correlation coefficient, ICC; standard error of measurement, SEM) were calculated
28 for first attempt, maximal attempt, and average across three trials. For all three methods,
29 Optojump correlated highly to the FP (range $r = 0.98-0.99$) with small bias (range 0.91-0.92,
30 95%LoA 0.86-0.98). Myotest demonstrated high correlation to FP (range $r = 0.81-0.86$) with
31 larger bias (range 1.92-1.93, 95%LoA 1.63-2.23). Optojump yielded a low CV (range 5.9%-
32 6.8%), high ICC (range 0.82-0.86) and SEM ranging 1.8-2.1 kN/m. Myotest had a larger CV
33 (range 8.9%-13.0%), moderate ICC (range 0.64-0.79) and SEM ranging from 6.3-8.9 kN/m. The
34 findings present important information for these devices and support the use of a time efficient
35 single trial to assess leg stiffness in the field.

36

37 **Keywords:** hopping test, vertical stiffness, test-retest, sensitivity.

38

39 **Word Count:** 2043

40

Introduction

41 Leg stiffness describes the response of the lower limbs to generate force and resist
42 deformation during rebound activities.^{8,9} Enhanced stiffness is beneficial to reduce metabolic cost
43 of bouncing gait (i.e. running, hopping)¹²⁻¹⁴ as well as to attaining high sprinting speed¹⁵⁻¹⁶,
44 whereas lower leg stiffness may lead to less storage and recoil of elastic energy, placing greater
45 metabolic demand during push-off, and to a reduced ability to sustain impact loads, raising injury
46 risk.^{9,11,17}

47 Two field-based devices that can assess leg stiffness are the Optojump Next[®] (Microgate,
48 Bolzano, Italy) and Myotest Pro[®] (Myotest, Sion, Switzerland).²¹⁻²² Optojump is an optical
49 measurement system consisting of two infrared photocell bars that can derive contact and flight
50 times from the breaking of the transmitted beam, whereas Myotest is a wireless lightweight
51 portable triaxial accelerometer that can be fixed on the athlete. Both are portable and practical,
52 allowing athletes to jump on any given surface, used largely because of their versatility and
53 reasonable cost.²³⁻²⁵

54 The aim of the present study was twofold. Criterion-related validity, reliability and
55 sensitivity of Optojump and Myotest for measuring leg stiffness in hopping were assessed. These
56 aspects were then examined with three different procedures: the first trial executed, the average
57 across three trials, and the maximal stiffness value, to explore whether a single trial is sufficient.

58

Methods

59 **Participants**

60 Thirty-four males (age 21.8 ± 3.9 years, height 1.83 ± 0.07 m, mass 79.0 ± 11.4 kg) took
61 part in the study. They were physically active and free from lower limbs injuries for at least six
62 months prior. Participants were instructed to refrain from strenuous exercise, alcohol, and
63 caffeine for 2 days, 24 and 2 hours before testing, respectively. Procedures were approved by the
64 University Ethical Committee and informed consent was given by all participants.

65 **Procedures**

66 Participants visited the laboratory twice, 1 week apart, at the same time of the day.
67 Following a standardised warm up, participants were familiarised with the test. Following a 5-
68 minute rest, 3 trials of the 7MH were performed, with 2 minutes resting between trials.
69 Participants were instructed to jump as high as possible, with minimal contact time, and with
70 arms akimbo at all times

71 All jumps were performed on a force platform (FP) (AccuPower, AMTI, Watertown, MA,
72 United States; 200 Hz sampling rate). Average contact and flight times from all jumps, and
73 participants' body mass, obtained from the resulting vertical force-time trace, were used to
74 calculate leg stiffness.¹⁸

$$\text{Leg stiffness} = \frac{\text{Mass} \times \pi (\text{flight time} + \text{contact time})}{\text{contact time}^2 \times \left(\left(\frac{\text{flight time} + \text{contact time}}{\pi} \right) - \left(\frac{\text{contact time}}{4} \right) \right)} \quad (\text{Eq. 1})$$

75 Data were synchronously collected by Optojump and Myotest (Figure 1). Optojump 1-
76 meter bars (resolution of 96 diodes, 1 kHz sampling rate) were placed on the lateral edges of the
77 FP. Average contact and flight times from all jumps and the participant's body mass was used in
78 Eq. 1 to calculate leg stiffness.¹⁸ Myotest (500 Hz sampling rate) was fixed on the participants

79 with an elastic Velcro waistband, fastened around both great trochanters and the medium part of
80 the gluteal region, as per manufacturer instructions. Myotest calculates leg stiffness taking into
81 account the average of the best three hops from any given trial. Leg stiffness values were
82 displayed on the device screen immediately after the trial.

83 **Data Analysis**

84 Leg stiffness was examined for all three devices from a) the 1st trial from each session
85 (K_{First}), b) the average across three trials from each session (K_{Avg}), and c) the maximal value from
86 each session (K_{Max}).

87 For the K_{Max} approach, Wilcoxon signed-rank test was used to check for conformity of the
88 trial number wherein the maximum stiffness value occurred between each device and FP,
89 revealing no significant difference for any comparison. For the K_{Avg} approach, within-subject
90 variation over the three trials was assessed via 1-way repeated measures ANOVA before
91 averaging, reporting no significant differences. Therefore, stiffness results for each subject were
92 collapsed to a single value per session.

93 **Criterion-related validity assessment procedures**

94 As no significant test-retest differences (examined with paired t -test) between the 1st and
95 2nd sessions were reported for any of the devices, results were collapsed to a single participant
96 value for each of the K_{First} , K_{Max} , and K_{Avg} procedures,²⁸ which were then used for criterion-
97 related validity of the Optojump and Myotest in comparison to the FP. Data was checked for
98 heteroscedasticity by correlating the test score differences between either Optojump or Myotest
99 and the FP to their mean value, for each procedure.²⁹ As significant correlations were found, raw
100 data was transformed using the natural logarithm before further analysis occurred.²⁹ Normality of
101 residuals (log test score differences between either Optojump or Myotest and FP) was confirmed

102 for each device and procedure using the Shapiro-Wilk test, with normality defined as the ratio of
103 skewness and kurtosis to the respective standard error not exceeding ± 2.0 .³⁰ Criterion-related
104 validity of each device to the FP was assessed via Pearson's correlation coefficient and relative
105 mean bias. Additionally, 95% limits of agreement (95%LoA) were reported.²⁹ Pearson's
106 correlation coefficient (r) was interpreted as indicating high correlation for an r value above 0.8.³¹
107 Relative mean bias was calculated as the difference between the logarithmic transformed score
108 means of either Optojump or Myotest and FP, and reported as antilog, meaning it was interpreted
109 as the ratio between the average outcome of the examined device and that of the FP. Likewise,
110 95%LoA were calculated on the logarithmic scale, and reported as antilogs as mean difference \pm
111 1.96 standard deviations of the differences.

112 **Reliability assessment procedures**

113 The residuals (raw 1st – 2nd session score differences) and the respective pair means for
114 each piece of equipment and procedures were correlated allowing homoscedastic distribution to
115 be confirmed. Thus, data was further analyzed as raw values. Normality of the residuals was then
116 confirmed for each procedure and device.

117 Indices of both absolute and relative reliability were used for the investigation, for each
118 procedure. Absolute intersession reliability was assessed via coefficient of variation and standard
119 error of measurement (CV and SEM, respectively). The CV threshold was set at 10%, with
120 values below suggesting high consistency.^{33,34} SEM was calculated as the square root of the
121 mean square error term in a repeated measures ANOVA.³⁰ SEM is of practical importance,
122 allowing coaches to determine the minimum difference (MD; Eq. 2) needed for a performance
123 change to be considered real (95% confidence) rather than a measurement error^{30,35}

$$\text{MD} = \text{SEM} \times 1.96 \times \sqrt{2} \quad (\text{Eq. 2})$$

124
125 Finally, relative intersession reliability was assessed by interclass correlation coefficient
126 (ICC), calculated as³⁶:

$$127 \quad ICC = 1 - \left(\frac{SEM^2}{\text{mean of subjects' standard deviation between trials}^2} \right) \quad (\text{Eq. 3})$$

128
129 The threshold was set at 0.8, with values above indicating small measurement error.³⁷
130 95% confidence intervals for ICCs were also calculated.³⁸

131 Statistical significance level was set at $P < 0.05$. All statistical tests were performed using
132 SPSS software (IBM SPSS Statistics, version 20, Inc., Chicago, IL, USA).

133 Results

134 Leg stiffness calculated from Optojump demonstrated high correlation to FP (Table 1) in
135 all analysis procedures (range $r = 0.98-0.99$, $P < .001$) with bias ranging from 0.91 to 0.92 (Table
136 2). 95%LoA (Table 2, Figure 2) were not substantially different between procedures. Leg
137 stiffness calculated from Myotest (Table 1) also showed high correlation to leg stiffness
138 calculated from FP in all methods (range $r = 0.81 - 0.86$, $P < .001$). However, bias ranged
139 between 1.92 and 1.93 (Table 2), resulting in increased 95%LoA (Figure 2).

140 FP exhibited low CV, suggesting good absolute reliability (Table 3). However, when
141 relative reliability was considered, only K_{Max} procedure reported an $ICC \geq 0.8$, with K_{First} and
142 K_{Avg} ICCs of 0.74 and 0.79, respectively. Optojump revealed high absolute and relative reliability
143 in all three analysis procedures, shown from relatively low values of group mean CV and high
144 ICC (Table 3). For Myotest, the K_{Avg} procedure was the more consistent with a low CV but
145 moderate ICC, whereas K_{First} and K_{Max} reported lower consistency (Table 3).

146 For all procedures, Myotest yielded higher SEM than the FP and Optojump (Table 3).

147 **Discussion**

148 The aim of this study was to determine criterion-related validity and reliability of two
149 commonly used field-based devices (i.e. Optojump and Myotest) in measuring leg stiffness. In
150 addition, three different analysis procedures were examined (i.e. K_{First} , K_{Max} and K_{Avg}), to provide
151 practical information in terms of timing requirements to assess leg stiffness. Optojump showed a
152 valid leg stiffness measurement compared to FP, with all analysis procedures being reliable.
153 Myotest also showed valid leg stiffness measurement compared to FP, but with moderate
154 reliability for all three procedures.

155 Leg stiffness values measured with Optojump agreed well with the FP values and are
156 within the range reported from previous literature.^{10,18-20} When the three different procedures
157 were considered, all showed high reliability, with similar indexes to earlier research using the
158 FP.^{39,40} The systematic bias of Optojump was most likely due to the placement of Optojump bars
159 on the FP (Figure 1), meaning the infrared beams were 0.3 cm higher than the FP surface,²⁶
160 resulting in increased contact time and reduced flight time compared to those of FP, in turn lower
161 leg stiffness.^{4,18} Although this height discrepancy may appear as a methodological concern, this
162 approach was adopted as in field testing, the beams will inherently be raised on a given surface
163 (e.g. ground, court, track).

164 Leg stiffness values obtained from Myotest were significantly greater than the FP and
165 outside the values seen from hopping in previous reports.^{10,18-20} Further, reliability for all three
166 procedures was moderate. Our results contradict the study by Choukou et al.²² who reported the 5
167 hop test as valid and reliable in measuring leg stiffness using Myotest. The higher number of
168 total hops considered in Choukou et al.²² (all 5, compared to best 3 in the present investigation)

169 could have reduced within-subject variability³⁶. The overestimation of leg stiffness and poorer
170 reliability of Myotest in relation to the FP might be attributed firstly to the Myotest leg stiffness
171 computation being based on integration of acceleration, with respect to mass and time, and
172 establishes the time interval of integration when the accelerations are null.²² As maximal
173 descending and ascending velocities are not achieved at those exact points, contact time and
174 centre of mass displacement are underestimated, while flight time, force and jump height are
175 overestimated^{22,24}; in turn, magnifying leg stiffness values. Secondly, the fast transition between
176 braking and push-off phase during the maximal hopping task is likely to have caused vibrations
177 of the device and in turn erroneous acceleration detections.

178 High sensitivity of a device allows for better determining differences resulting from true
179 changes of the physical characteristic evaluated rather than from a measurement error.^{35,42} For
180 this purpose, we calculated SEM, to determine MD and construct confidence intervals, which can
181 detect, with 95% confidence, real changes in the variable being measured. The importance of
182 this is illustrated in the following example. Let us assume that an athlete achieves a stiffness
183 score of 25 kN/m at pre-intervention assessment, and a value of 33kN/m at post-intervention
184 assessment. Replacing the respective SEM from the K_{First} procedure (Table 3) in Eq. 2, the MD
185 will be 5.8 kN/m for Optojump and 21.1 kN/m for Myotest. As the test-retest difference (8 kN/m)
186 lies outside the MD for Optojump, we would be confident of a true increase post-intervention,
187 whereas we would be unable to reach a conclusion using Myotest.

188 Assessing many athletes within the time-restrictions of a training or an assessment
189 session, requires use of scientifically rigorous methods and consideration of the the practical
190 aspects of the assessment (e.g. time availability, set-up and feedback time). Our results showed
191 that leg stiffness assessment can be completed in a valid and reliable manner in the field. Further,

192 leg stiffness can be confidently assessed with the use of a single trial, allowing time-efficient
193 testing, in particular short time frames are available or large populations are to be tested.

194 **References**

- 195 1. Blickhan R. The spring-mass model for running and hopping. *J Biomech.* 1989;22(11–
196 12):1217-1227. [http://dx.doi.org/10.1016/0021-9290\(89\)90224-8](http://dx.doi.org/10.1016/0021-9290(89)90224-8)
- 197 2. McMahon TA, Cheng GC. The mechanics of running: how does stiffness couple with
198 speed? *J Biomech.* 1990;23(Suppl. 1):65-78. [http://dx.doi.org/10.1016/0021-9290\(90\)90042-2](http://dx.doi.org/10.1016/0021-9290(90)90042-2)
- 199 3. Farley CT, Gonzales O. Leg stiffness and stride frequency in human running. *J Biomech.*
200 1996;29:181-186. [http://dx.doi.org/10.1016/0021-9290\(95\)00029-1](http://dx.doi.org/10.1016/0021-9290(95)00029-1)
- 201 4. Farley CT, Morgenroth DC. Leg stiffness primarily depends on ankle stiffness during
202 human hopping. *J Biomech.* 1999;32(3):267-273. [http://dx.doi.org/10.1016/S0021-9290\(98\)00170-5](http://dx.doi.org/10.1016/S0021-9290(98)00170-5)
- 203 5. Hobara H, Muraoka T, Omuro K, et al. Knee stiffness is a major determinant of leg
204 stiffness during maximal hopping. *J Biomech.* 2009;42(11):1768-1771.
205 <http://dx.doi.org/10.1016/j.jbiomech.2009.04.047>
- 206 6. Kuitunen S, Ogiso K, Komi PV. Leg and joint stiffness in human hopping. *Scand J Med
207 Sci Sports.* 2011;21(6):e159-e167. doi: 10.1111/j.1600-0838.2010.01202.x
- 208 7. Farley C, Houdijk H, Van Strien C, Louie M. Mechanism of leg stiffness adjustment for
209 hopping on surfaces of different stiffnesses. *J Appl Physiol.* 1998;85(3):1044-1055.
- 210 8. Bobbert MF, Casius LJR. Spring-like leg behaviour, musculoskeletal mechanics and
211 control in maximum and submaximum height human hopping. *Philos Trans R Soc Lond B
212 Biol Sci.* 2011; 366(1570):1516-1529. <http://dx.doi.org/10.1098/rstb.2010.0348>
- 213
214

- 215 9. Oliver JL, Croix MBADS, Lloyd RS, Williams CA. Altered neuromuscular control of leg
216 stiffness following soccer-specific exercise. *Eur J Appl Physiol.* 2014;114(11):2241-2249.
217 doi: [10.1007/s00421-014-2949-z](https://doi.org/10.1007/s00421-014-2949-z)
- 218 10. Hobara H, Kanosue K, Suzuki S. Changes in muscle activity with increase in leg stiffness
219 during hopping. *Neurosci Lett.* 2007;418(1):55-59.
220 <http://dx.doi.org/10.1016/j.neulet.2007.02.064>
- 221 11. Kuitunen S, Kyröläinen H, Avela J, Komi PV. Leg stiffness modulation during exhaustive
222 stretch-shortening cycle exercise. *Scand J Med Sci Sports.* 2007;17(1):67-75. doi:
223 [10.1111/j.1600-0838.2005.00506.x](https://doi.org/10.1111/j.1600-0838.2005.00506.x).
- 224 12. Oliver JL, Smith PM. Neural control of leg stiffness during hopping in boys and men. *J*
225 *Electromyogr Kinesiol.* 2010;20(5):973-979.
226 <http://dx.doi.org/10.1016/j.jelekin.2010.03.011>
- 227 13. Dalleau G, Belli A, Bourdin M et al. The spring-mass model and the energy cost of
228 treadmill running. *Eur J Appl Physiol.* 1998, 77:257-263. doi: [10.1007/s004210050330](https://doi.org/10.1007/s004210050330).
- 229 14. Barnes KR, Hopkins WG, McGuigan MR, Kilding AE. Warm-up with a weighted vest
230 improves running performance via leg stiffness and running economy. *J Sci Med Sport.*
231 2015;18(1):103-108. <http://dx.doi.org/10.1016/j.jsams.2013.12.005>.
- 232 15. Chelly SM, Denis C. Leg power and hopping stiffness: relationship with sprint running
233 performance. *Med Sci Sports Exerc.* 2001;33(2):326-33. doi: [10.1097/00005768-](https://doi.org/10.1097/00005768-200102000-00024)
234 [200102000-00024](https://doi.org/10.1097/00005768-200102000-00024).
- 235 16. Bret C, Rahmani A, Dufour AB, et al. Leg strength and stiffness as ability factors in 100
236 m sprint running. *J Sports Med Phys Fitness.* 2002;42(3):274-81.
- 237 17. Rabita G, Couturier A, Dorel S, et al. Changes in spring-mass behavior and muscle
238 activity during an exhaustive run at O₂max. *J Biomech.* 2013;46(12):2011-2017.

- 239 <http://dx.doi.org/10.1016/j.jbiomech.2013.06.011>
- 240 18. Dalleau G, Belli A, Viale F, et al. A simple method for field measurements of leg stiffness
241 in hopping. *Int J Sports Med.* 2004;25:170-176. doi: 10.1055/s-2003-45252.
- 242 19. Lloyd RS, Oliver JL, Hughes MG, Williams CA. Reliability and validity of field-based
243 measures of leg stiffness and reactive strength index in youths. *J Sports Sci.*
244 2009;27(14):1565-1573. doi: 10.1080/02640410903311572.
- 245 20. Lloyd RS, Oliver JL, Hughes MG, Williams, CA. The effect of 4-weeks of plyometric
246 training on reactive strength index and leg stiffness in male youths. *J Strength Cond Res.*
247 2012;26(10):2812-2819. doi:10.1519/JSC.0b013e318242d2ec.
- 248 21. Maquirriain J. The interaction between the tennis court and the player: how does surface
249 affect leg stiffness?. *Sports Biomech.* 2013;12(1):48-53.
250 doi:10.1080/14763141.2012.725088.
- 251 22. Choukou MA, Laffaye G, Taiar R. Reliability and validity of an accelerometric system
252 for assessing vertical jumping performance. *Biol Sport.* 2014;31(1):55-62.
253 doi:10.5604/20831862.1086733.
- 254 23. Girard O, Lattier G, Micallef JP, Millet GP. Changes in exercise characteristics, maximal
255 voluntary contraction, and explosive strength during prolonged tennis playing. *Br J Sports*
256 *Med.* 2006;40(6):521-526. doi:10.1136/bjism.2005.023754.
- 257 24. Casartelli N, Müller R, Maffiuletti NA. Validity and reliability of the Myotest
258 accelerometric system for the assessment of vertical jump height. *J Strength Cond Res.*
259 2010;24(11):3186-93. doi: 10.1519/JSC.0b013e3181d8595c.
- 260 25. Castagna C, Ganzetti M, Ditroilo M, et al. Concurrent validity of vertical jump
261 performance assessment systems. *J Strength Cond Res.* 2013;27(3):761-768. doi:
262 10.1519/JSC.0b013e31825dbcc5.

- 263 26. Glatthorn JF, Gouge S, Nussbaumer S, et al. Validity and reliability of Optojump Next
264 photoelectric cells for estimating vertical jump height. *J Strength Cond Res.*
265 2011;27(3):761-8. doi: [10.1519/JSC.0b013e3181ccb18d](https://doi.org/10.1519/JSC.0b013e3181ccb18d).
- 266 27. Bampouras TM, Relph NS, Orme D, Esformes JI. Validity and reliability of the Myotest
267 Pro wireless accelerometer in squat jumps. *Isokinet Exerc Sci.* 2013;21:101-105. doi:
268 [10.3233/IES-130484](https://doi.org/10.3233/IES-130484).
- 269 28. Thompson CJ, Bembien MG. Reliability and comparability of the accelerometer as a
270 measure of muscular power. *Med Sci Sports Exerc.* 1999;31(6):897-902.
271 doi: [10.1097/00005768-199906000-00020](https://doi.org/10.1097/00005768-199906000-00020).
- 272 29. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods
273 of clinical measurement. *Lancet.* 1986;1:307-310. [http://dx.doi.org/10.1016/S0140-](http://dx.doi.org/10.1016/S0140-6736(86)90837-8)
274 [6736\(86\)90837-8](http://dx.doi.org/10.1016/S0140-6736(86)90837-8).
- 275 30. Vincent WJ, Weir JP. *Statistics in kinesiology*. 4th ed. Champaign, IL: Human Kinetics;
276 2012.
- 277 31. Cohen J. *Statistical power analysis for the behavioural sciences*. 2nd ed. Mahwah, NJ:
278 Lawrence Erlbaum; 1988.
- 279 32. Sale DG. Testing strength and power. In: MacDougall JD, Wenger HA, Green HJ, eds.
280 *Physiological testing of the high performance athlete*. 2nd ed. Champaign, IL: Human
281 Kinetics; 1991: 21-106.
- 282 33. Atkinson G, Nevill AM. Statistical method for assessing measurement error (reliability)
283 in variables relevant to sports medicine. *Sports Med.* 1998;26(4):217-238. doi:
284 [10.2165/00007256-199826040-00002](https://doi.org/10.2165/00007256-199826040-00002).

- 285 34. O’Leary TJ, Morris MG, Collett J, Howells K. Reliability of single and paired-pulse
286 transcranial magnetic stimulation in the vastus lateralis muscle. [published online ahead
287 of print January 23, 2015]. *Muscle Nerve*. doi: 10.1002/mus.24584.
- 288 35. Hopkins WG. How to interpret changes in an athletic performance test. *Sportscience*.
289 2004;8:1-7.
- 290 36. Hopkins WG. Measures of reliability in sports medicine and science. *Sports Med*.
291 2000;30(1):1-15. doi: 10.2165/00007256-200030010-00001.
- 292 37. Nunnally J, Bernstein I. *Psychometric Theory*. 3rd ed. New York, NY: McGraw Hill;
293 1993.
- 294 38. Hopkins WG. Calculating the reliability intraclass correlation coefficient and its
295 confidence limits (Excel spreadsheet). 2009.
296 <http://www.sportsci.org/resource/stats/xICC.xls>
- 297 39. Joseph CW, Bradshaw EJ, Kemp J, Clark RA. The interday reliability of ankle, knee, leg,
298 and vertical musculoskeletal stiffness during hopping and overground running. *J Appl*
299 *Biomech*. 2013;29:386-394.
- 300 40. McLachlan KA, Murphy AJ, Watsford ML, Rees S. The interday reliability of leg and
301 ankle musculotendinous stiffness measures. *J Appl Biomech*. 2006;22:296-304.
- 302 41. Komi PV, Nicol C. Stretch-shortening cycle of muscle function. In: Komi PV, ed.
303 *Neuromuscular aspects of sport performance*. Oxford, UK: Blackwell Science Ltd;
304 2011:15-31.
- 305 42. Weir JP. Quantifying test-retest reliability using the intraclass correlation coefficient and
306 the SEM. *J Strength Cond Res*. 2005;19(1):231-240.

308 **Table1.** Leg stiffness (mean \pm SD) for Session 1 and Session 2.

		Leg Stiffness (kN/m)	
		Session 1	Session 2
K_{First}	FP	26.3 \pm 5.1	26.6 \pm 5.6
	Optojump	24.2 \pm 4.4	24.2 \pm 5.1
	Myotest	53.0 \pm 15.2	50.7 \pm 14.0
K_{Avg}	FP	26.0 \pm 5.2	26.2 \pm 5.0
	Optojump	24.1 \pm 4.6	23.9 \pm 4.4
	Myotest	52.0 \pm 14.3	50.2 \pm 12.4
K_{Max}	FP	27.6 \pm 5.6	27.6 \pm 5.9
	Optojump	25.1 \pm 4.7	24.8 \pm 5.4
	Myotest	55.0 \pm 15.1	51.8 \pm 13.6

309 *Note.* First attempt procedure (**K_{First}**); maximal value procedure (**K_{Max}**); session average value310 procedure (**K_{Avg}**); force platform (FP).

311 **Table 2.** Criterion-related validity statistics, compared to FP.

		r	Relative mean bias	95% LoA
K_{First}	Optojump	0.99	0.91	0.86 – 0.96
	Myotest	0.82	1.93	1.63 – 2.23
K_{Avg}	Optojump	0.99	0.92	0.86 – 0.98
	Myotest	0.86	1.92	1.64 – 2.19
K_{Max}	Optojump	0.98	0.92	0.87-0.97
	Myotest	0.81	1.93	1.67 – 2.19

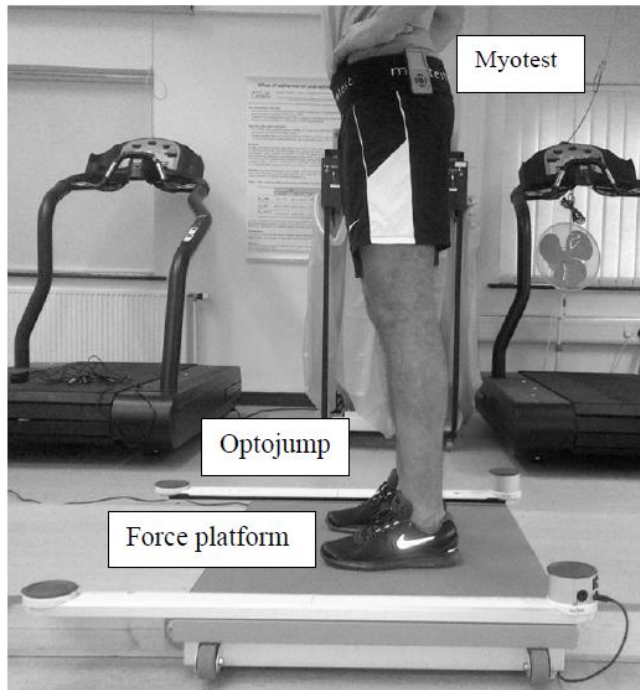
312 *Note.* First attempt procedure (**K_{First}**); maximal value procedure (**K_{Max}**); session average value
 313 procedure (**K_{Avg}**); force platform (FP); Pearson’s product moment correlation coefficient (r);
 314 limits of agreement (LoA). All r values were statistically significant at the level of $P < .001$.

315 **Table 3.** Test-retest reliability statistics for every device

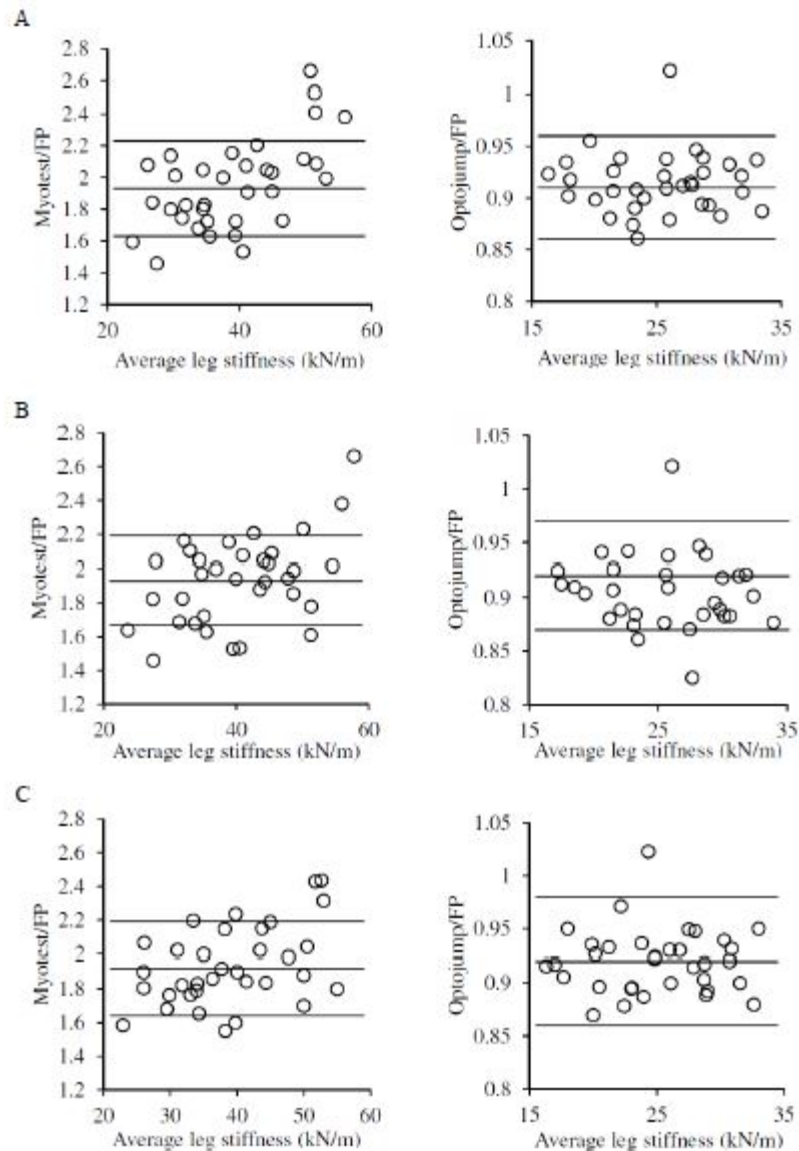
		CV ± SD (%)	SEM (kN/m)	ICC (95% CI)
K_{First}	FP	7.7 ± 7.5	2.8	0.74 (0.57 - 0.84)
	Optojump	6.6 ± 5.4	2.1	0.82 (0.70 – 0.90)
	Myotest	12.4 ± 7.0	7.6	0.74 (0.57 – 0.84)
K_{Avg}	FP	6.5 ± 7.7	2.4	0.79 (0.64 – 0.88)
	Optojump	5.9 ± 5.2	1.8	0.86 (0.74 – 0.92)
	Myotest	8.9 ± 7.1	6.3	0.79 (0.64 – 0.88)
K_{Max}	FP	7.3 ± 7.8	2.6	0.80 (0.66 – 0.88)
	Optojump	6.8 ± 6.7	2.1	0.83 (0.71 – 0.90)
	Myotest	13.0 ± 9.4	8.7	0.64 (0.44 – 0.78)

316 *Note.* First attempt procedure (**K_{First}**); maximal value procedure (**K_{Max}**); session average value
 317 procedure (**K_{Avg}**); force platform (**FP**); intraclass correlation coefficient (**ICC**); confidence
 318 intervals (**CI**); coefficient of variation (**CV**); standard deviation (**SD**); standard error of
 319 measurement (**SEM**).

320



329 **Figure 1.** Experimental setup of the devices for synchronous data collection. Note that, custom-
330 made wooden blocks were aligned behind and ahead of the force platform.



331
 332 **Figure 2.** Limits of agreement. Ratio of leg stiffness measurements outcome between either
 333 Myotest (left side) or Optojump (right side) and Force platform (FP), plotted against their
 334 average. The continuous line represents the mean relative bias between the examined device and
 335 the FP. Dashed lines represents lower and upper limits with 95 % confidence. A) The 1st trial per
 336 session was considered (K_{First}). B) The average across the three trials per session was retained
 337 (K_{Avg}). C) The maximal stiffness value per session was considered (K_{Max}).