

TITLE

Reciprocal versus non-reciprocal assessment of knee flexors and 1 extensors in concentric actions using the CON-TREX multi-joint 2 isokinetic dynamometer: A reliability study

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1 **Reciprocal versus non-reciprocal assessment of knee flexors and**
2 **extensors in concentric actions using the CON-TREX multi-joint**
3 **isokinetic dynamometer: A reliability study**

4 Knee flexor and extensor muscular assessment via isokinetic dynamometry is
5 common practice and established in the research literature. However, reporting
6 assessment methodology regarding reciprocal and non-reciprocal movements is
7 often vague or absent. Such methodological issues are crucial for accurate
8 assessments. Therefore, knee extensor and flexor peak moment using either
9 reciprocal movement or non-reciprocal modalities was assessed. Fifteen
10 participants performed 3 blocks of 5 concentric muscle actions at three angular
11 velocities [1: non-reciprocal (maximal active flexion followed by passive
12 extension); B2: reciprocal (maximal active extension followed by maximal active
13 flexion); B3 non-reciprocal (maximal active extension followed by passive
14 flexion)]. ANOVA revealed statistically significant within-subject modality
15 effects for peak knee extensor moment and flexor velocity and modality
16 differences ($P < 0.05$). Reciprocal and non-reciprocal assessments give
17 significantly different results, with non-reciprocal giving higher peak moments.
18 Reporting which modality is used is crucial to allow for greater clarity for the
19 reader and practitioner.

20 **Keywords:** Isokinetic, peak moment, quadriceps, hamstrings, muscular
21 assessment

22

23

24 **Introduction**

25

26 Injuries to the musculature of the thigh are amongst the most common injuries
27 observed in a wide range of sports and exercise settings. This is particularly so in
28 sports with intermittent activity profiles and other team sports involving sprinting and
29 kicking (Arnason, Andersen, Holme, Engebretsen, & Bahr, 2008). Isokinetic
30 dynamometry is a frequently utilised tool when assessing the strength of the thigh to
31 identify a patient's injury risk and is considered the gold standard for dynamic muscle
32 strength testing (Wollin, Purdam, & Drew, 2016).

33

34 Muscular strength imbalance has been postulated as a potential precursor to injury
35 (Strauss, Allen, Munt, & Zanoli, 1996). A knee flexion/extension ratio utilising
36 concentric muscle actions of 0.6 at $60^{\circ}\cdot s^{-1}$ is considered to represent normal knee
37 function (Aagard, Simonsen, Trolle, Bangsbo, & Klausen, 1995). Despite abundant
38 literature into the area, the relationship between muscle injury and strength imbalance
39 remains controversial (Croisier, Ganteaume, Binet, Genty, & Ferret, 2008). A
40 possible suggestion for this is difficulty with data interpretation. There are frequent
41 inconsistencies in the research literature with regards to the application of isokinetic
42 measurement (velocity of movement, number of repetitions, muscle action type,
43 testing position etc.) which makes interpretation of data more challenging (Gleeson
44 & Mercer, 1996; Undheim, Cosgrave, King, Strike, Marshall, Faley, & Franklin-
45 Miller, 2015), even when the dynamometers exhibit very high mechanical reliability
46 (Caruso, Brown, & Tufano, 2012).

47

48 Few studies outline whether the movement modality used for assessment of the thigh
49 musculature (knee extension/flexion) are conducted reciprocally or as separate
50 movements (reciprocal = extension followed by flexion. Non-reciprocal =
51 extension/flexion followed by rest) (Caruso et al., 2012). Even in a recent meta-
52 analysis which discussed isokinetic assessment of the knee musculature at length,
53 consideration to reciprocal and non-reciprocal movement was not discussed
54 (Undheim et al., 2015). Reciprocal assessment allows for multiple movements to be
55 performed in series as where the non-reciprocal assessment modality requires a
56 “passive” movement in either flexion or extension which is followed by a voluntary
57 muscle action (Strauss, Allen, Munt, & Zanoli, 1996).

58

59 Therefore, the purpose of the present study was to conduct test-retest reliability
60 measures of three commonly used velocities, using concentric muscle actions to
61 identify whether testing modality, velocity, or day significantly influence moment
62 production at the knee in resistance-trained, male participants.

63

64 **Material and Method**

65 **Participants**

66 Fifteen resistance-trained, male participants were recruited (age = 23.2 ± 3.7
67 years, stature = 179 ± 6 cm, body mass = 79.3 ± 9.4 kg). Participants had never
68 previously performed a strength assessment using isokinetic dynamometry.
69 Participants were uninjured, had not previously sustained injury to the thigh or knee,
70 and were undertaking moderate to vigorous physical activity of >30 minutes in
71 duration at least five times per week, with at least one of those sessions being
72 resistance training. All participants completed a medical questionnaire and were

73 provided with an information sheet about the research. Verbal information was given
74 to each subject on the assessment day to finalise the informed consent procedure.
75 Participants signed a declaration to confirm they consented to testing and could
76 withdraw at any time. Approval for the study was granted by the University's ethics
77 committee in accordance with the Declaration of Helsinki.

78

79 **Experimental Procedure**

80 Participants visited the laboratory on two occasions, seven days apart, at the same
81 time of day. Participants were asked to maintain their regular diet, with no caffeine or
82 alcohol 24 hours and no exhaustive exercise at least 48 hours prior to assessment. On
83 arrival, participants underwent a standard anthropometric assessment. The isokinetic
84 dynamometry test procedure involved dominant (as determined by preferred kicking
85 leg (Greig, 2008) assessment only and only concentric muscle actions were
86 performed. Participants were allowed a warm up of 20 repetitions at $120^{\circ}\cdot\text{s}^{-1}$.
87 Participants were asked to work at an estimated intensity of 50 to 90% with the final
88 effort close to 100% throughout the warm up period.

89

90 The main protocol consisted of three blocks of three sets of five repetitions and is
91 shown in Figure 1. One set comprised either: 5 maximal active flexions followed by
92 passive extensions (non-reciprocal); or 5 maximal active extension and flexion
93 (reciprocal); or 5 maximal active extensions followed by passive flexions (non-
94 reciprocal). Passive movements in the non-reciprocal assessment modality were
95 performed at $60^{\circ}\cdot\text{s}^{-1}$. Each set was interspersed with 60 seconds rest. Upon
96 completion of each set, the participant was afforded a five-minute rest period whilst
97 the velocity of movement was altered. The order of movement velocity was $180^{\circ}\cdot\text{s}^{-1}$,

98 300°·s⁻¹, and 60°·s⁻¹. This was used to minimise any order effect owing to a perception
99 of accommodation and increased importance of latter trials if a progressive velocity
100 pattern was followed (Greig, 2008).

101 [Figure 1 here]

102

103 A CON-TREX multijoint isokinetic dynamometer (CON-TREX MJ; CMV AG,
104 Dübendorf, Switzerland) was used for evaluation of the knee flexors and extensors
105 and set up as per the manufacturer instructions. Participants were seated with the
106 backrest at an angle of 80° with the torso restrained by cross-harnesses. The left leg
107 was restrained using a Velcro strap across the thigh which was secured to the seat.
108 The right leg was secured by a firm cylindrical foam pad attached to a steel brace
109 which was attached to the seat. The right ankle was secured with a padded Velcro
110 strap placed 2cm superior to the ankle lateral malleolus. The dynamometer was
111 aligned dynamically to the lateral epicondyle of the knee. Participants were asked to
112 cross their arms during the assessment and place their palms flat on their shoulders.

113

114 The CON-TREX assessment software calculated the gravity correction and assisted
115 with maintaining constant velocity during the movements termed “Active
116 Compensation”. Participants performed movements through 100° range of motion
117 from the point of furthest knee extension. The participants verbally confirmed to the
118 assessor the maximum range of extension that they would be willing to exert force.
119 All chair set up positions and ranges of motion were recorded during the first
120 assessment and replicated in the second assessment for each subject.

121

122 Peak moment (Nm) from each trial in each set was selected after a box-and-whisker
123 plot was employed to remove outliers from the data with any data outside of 1.5
124 multiples of the upper or lower quartiles eliminated. Typically, examples of
125 mechanical error that may lead to outliers in the data set include end range of motion
126 impact artefact or inertial effects (Drouin, Volovich-McLeod, Shultz, Gansneder, &
127 Perrin, 2004; Hill, Pramanik, & McGregor, 2005).

128

129 **Data and Statistical Analysis**

130 Mean and standard deviations (SD) (mean \pm SD) were calculated for all variables.
131 Data were assessed for normality and sphericity prior to statistical analysis. A
132 composite battery of reliability statistics including relative (Pearson's correlation
133 coefficients and intraclass correlations (ICC) and absolute (coefficient of variation
134 (CV) and limits of agreement) measures were implemented within this study to
135 improve the scientific robustness when evaluating peak moments (Hopkins, 2000).
136 Typical error of measurement (TEM) was calculated from the SD of the mean
137 difference between the peak moments in Test A and Test B then divided by $\sqrt{2}$
138 (Hopkins, 2000), and expressed as a mean CV (%). Meaningful differences between
139 related samples during both tests were evaluated using Cohen's *d* and confidence
140 intervals (CI) (Lakens, 2013). Effect size was categorised as small (0.2), medium (0.5)
141 and large (0.8) (Cohen, 1988). Pearson product moment correlation coefficient and
142 ICC were calculated and categorised as small (<0.3), moderate (0.3-0.6) and large
143 (>0.6).

144

145 A mixed-model, repeated measures ANOVA was selected to analyse the data using
146 SPSS (SPSS Inc., v.24.0, Chicago, IL, USA). Significant interactions were further

147 investigated with paired samples t-tests. Graphs were produced in Microsoft Excel
148 (Microsoft Office 2010, Microsoft, Seattle, USA) Statistical significance was set at
149 an alpha level of $P < 0.05$.

150 **Results**

151 (TABLE 1 HERE)

152 Between-day reliability measures displayed in Table 1 shows that large correlations
153 (ICC and $r \geq 0.6$) were present between all variables. Data from 1800 muscle actions
154 were recorded (60 per subject, per visit =120. 15 subjects =15*120=1800), 160
155 actions were removed via the outlier removal process.

156

157 ANOVA revealed no significant between-day effects across any assessment (Table
158 1). For knee extension trials there was a significant effect of velocity of movement on
159 peak moment ($F_{(2,28)} = 101.377$, $P < 0.05$). There was also significant within-subject
160 modality effect for the peak moment of the knee extensors between reciprocal and
161 non-reciprocal methods ($F_{(1,14)} = 24.508$ $P < 0.05$). For the knee flexors, ANOVA
162 revealed a significant difference in the velocity*modality condition ($F_{(2,28)} = 11.859$,
163 $P < 0.05$).

164

165 Table 2 and Figure 2 show group mean peak moments for extension and flexion trials.
166 Post hoc significant differences were observed between reciprocal and non-reciprocal
167 testing modalities for peak moment in all knee extension and flexion trials ($P < 0.05$)
168 except flexion at $180^\circ \cdot s^{-1}$ ($P > 0.05$). Cohen's d effect sizes were categorised as small
169 negative (< 0.2) for extension at $180^\circ \cdot sec^{-1}$, moderate negative for extension at $60^\circ \cdot s^{-1}$,
170 $300^\circ \cdot s^{-1}$, and moderate positive for flexion at $300^\circ \cdot s^{-1}$ (-0.24, -0.36, 0.41

171 respectively). A medium negative effect was observed for flexion trials at $60^{\circ}\cdot\text{s}^{-1}$ (= -
172 0.5)
173 (FIGURE 2 HERE)

174 **Discussion**

175 The study herein sought to investigate the test-retest reliability of concentric knee
176 flexion and extension at various velocities using reciprocal and non-reciprocal testing
177 modalities. This study shows that while assessment of the musculature of the thigh
178 during knee extension and flexion is reliable between days, peak moment occurs at
179 different velocities and crucially, whether using reciprocal or non-reciprocal
180 assessment. Non-reciprocal methods yield lower peak moments in the knee extensors
181 when acting concentrically but higher peak moments in the knee flexors, except at
182 high velocity. Importantly, this study suggests there is significant variation in peak
183 moment observed between reciprocal and non-reciprocal testing modalities,
184 particularly at higher velocities.

185

186 In a review, Caruso et al. stated that test-retest data variability is inherent to isokinetic
187 dynamometry assessment and is the most frequently cited problem (Caruso et al.,
188 2012). The results herein suggest that, whilst the velocity*modality interaction and
189 the variability in peak moment between reciprocal and non-reciprocal assessment is
190 statistically significant, the between day assessments using the same modality remain
191 reliable (Table 1, Figure 2). It may be possible to achieve consistent results across
192 tests if the assessment modality is carefully selected and if the angular velocity is
193 standardised and appropriate for the population being assessed. The present study
194 suggests reciprocal knee flexion yields a lower peak moment at low and moderate
195 velocities, but higher peak moment at high velocities, when compared to non-

196 reciprocal assessment. Therefore, it is likely that, if assessment of the knee flexors at
197 high velocity is required, that additional familiarisation trials may be necessary.

198

199 Previous comparisons of reciprocal and non-reciprocal assessments showed no
200 differences with a similar research design to the present study. However, the authors
201 were utilising slower movement velocities (maximum of $180^{\circ}\cdot s^{-1}$) and a different
202 dynamometer (Kin-Com) (Strauss et al., 1996). Of CON-TREX studies, it has been
203 shown that the test-retest reliability of the CON-TREX multi-joint system was high
204 during reciprocal knee extension and flexion at a range of velocities (ICC \Rightarrow 0.99,
205 CV<3.5%) (Maffiuletti, Bizzini, Desbrosses, Babault, & Munzinger, 2007).
206 However, the authors did not prescribe any non-reciprocal assessment except under
207 eccentric conditions.

208

209 Obtaining accurate peak moment data is critical as it is often used to form a strength
210 ratio between the knee extensors and flexors. The quadriceps/hamstrings strength
211 ratio has long been purported to be an indicator of susceptibility to injury, although
212 the exact mechanisms are not well understood and remain controversial (Croisier et
213 al., 2008). Andrade et al. (2012) suggest that in injured or recreational participants,
214 utilising slower angular velocities should result in increased reliability. The data
215 presented in the Andrade paper agrees with this report that as angular velocity
216 increases, the strength ratio widens (more contribution from the extensors). The
217 increased contribution from the quadriceps to distort the ratio at high angular
218 velocities has been demonstrated to occur in male and female athletes, from a range
219 of backgrounds, up to $180^{\circ}\cdot s^{-1}$ (Rosene, Fogarty, & Mahaffey, 2001). The present
220 study demonstrates that if utilising high velocity movements using non-reciprocal

221 methods, the increased moment from the knee extensors, and the reduced moment
222 from the knee flexors (in comparison to reciprocal methods) will likely distort this
223 ratio. Therefore, it is suggested that practitioners using isokinetic dynamometry to
224 interpret muscular strength data carefully consider the protocol adopted to provide the
225 most functionally relevant and reliable assessment.

226

227 Due to the sophistication of isokinetic dynamometry as a method for assessing
228 muscular strength, much faith is placed in the results obtained; yet they must be
229 reliable, valid, and sensitive to act as a diagnostic tool (Bohanon, 1998). While there
230 is abundant literature into isokinetic dynamometry and assessment of the knee,
231 information pertaining to specific protocol design, particularly concerning the use of
232 reciprocal and non-reciprocal methods is either vague or missing from the methods
233 sections of many scientific reports (Carvalho, Silva, Ronque, Goncalves, Philippaerts,
234 & Malina, 2011; Undheim et al., 2015). Clarification, as provided herein, as to the
235 role of utilising a reciprocal or non-reciprocal assessment modality could be crucial
236 to understanding and correctly analysing data obtained.

237

238 **Conclusion:**

239 Practitioners utilising isokinetic dynamometry for assessment of strength should
240 ensure that their data collection methods are robust. The data presented herein suggest
241 that, in resistance-trained participants, using non-reciprocal actions will result in
242 higher peak moment, expect for the knee flexors at high velocity. Reciprocal actions
243 show reliability between days, as do non-reciprocal trials. However, the peak
244 moments obtained using reciprocal and non-reciprocal methods are often significantly
245 different. Therefore, the accurate and consistent reporting of which modality is

246 utilised is encouraged to allow readers to better understand the results obtained.
247 Further research is required in other populations to ascertain whether reciprocal or
248 non-reciprocal assessment methods yield more reliable measures and therefore
249 provide more accurate estimation of injury potential.

250

251 **Conflict of Interest Statement**

252 No potential conflict of interest was reported by the authors. No funding was received
253 for this project.

254

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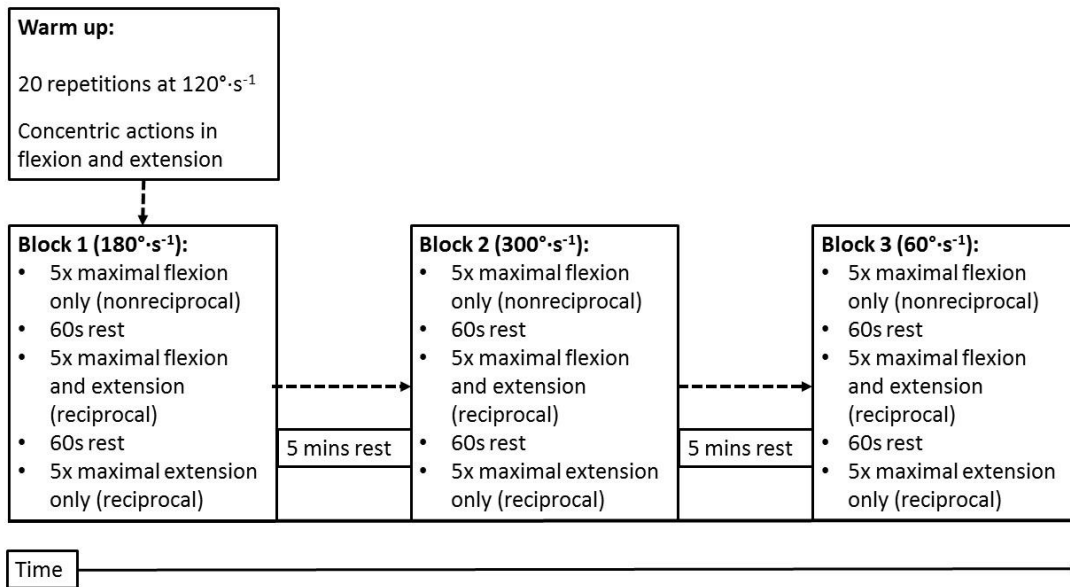
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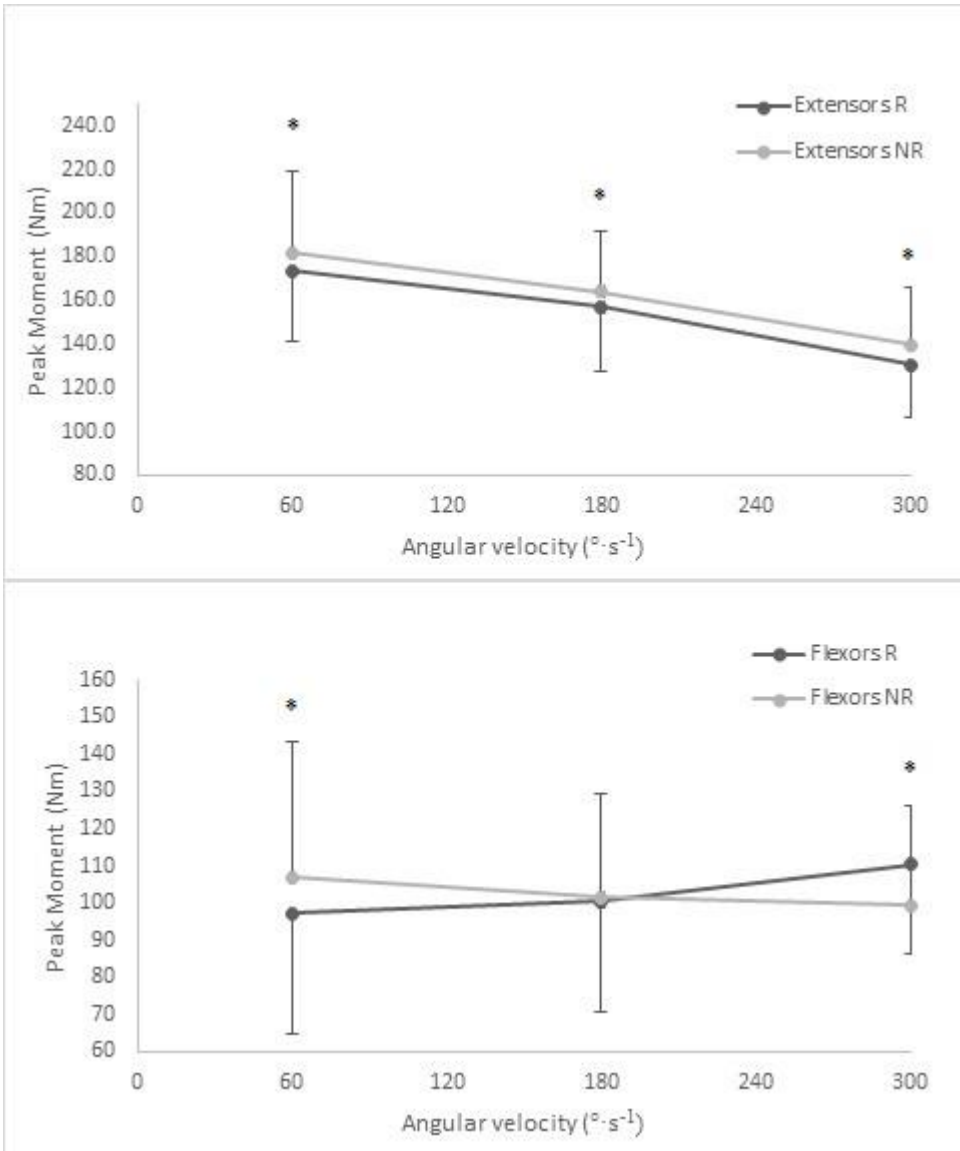
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354 Figure 1: Protocol design schematic



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356 Figure 2: Peak moment (Nm) for extensors (top) and flexors (bottom) during reciprocal
 357 and nonreciprocal modalities. Error bars represent SD. * = p < .05.

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Table 1: Between-day peak moments (Nm) for all velocities and modalities. Peak moment values are mean \pm SD

	Test A	Test B	Mean bias					
	(Nm)	(Nm)	(95% CI)	P	r	ICC	Cohen's d	TEM (CV %)
Ext60R	171.3 \pm 32	176.0 \pm 33.8	4.68 (-3.5, 12.9)	0.505	0.9	0.91	-0.15	10.5 (6.1)
Ext60NR	183.6 \pm 33.9	180.1 \pm 40.7	-3.53 (-14.6, 7.6)	0.240	0.87	0.88	0.1	14.2 (7.7)
Ext180R	158.7 \pm 32.6	155 \pm 27.4	-3.72 (-16.8, 9.4)	0.151	0.70	0.72	0.13	16.7 (10.8)
Ext180NR	165.9 \pm 29.1	162.0 \pm 27.7	-3.91 (-9.4, 1.6)	0.551	0.94	0.95	0.14	7.1 (3.7)
Ext300R	130.8 \pm 25.1	130.5 \pm 24.1	-0.31 (-7.7, 7.0)	0.984	0.86	0.87	0.01	9.4 (6.9)
Ext300NR	139.8 \pm 24.8	139.7 \pm 29.0	-0.1 (-5.72, 5.61)	0.928	0.94	0.94	0.00	7.2 (5.2)
Flex60R	94.9 \pm 17.2	99.4 \pm 19.1	4.5 (-3.1,12.0)	0.401	0.72	0.75	-0.26	9.7(10.0)
Flex60NR	109.1 \pm 22.3	104.6 \pm 20.9	-4.4 (-15.4, 6.5)	0.226	0.58	0.61	0.22	14.0 (13.0)
Flex180R	101.5 \pm 17.5	99.2 \pm 19.1	-2.3 (-12.3, 7.7)	0.448	0.52	0.55	0.13	12.7(13.6)
Flex180NR	100.2 \pm 18.5	103.1 \pm 19.5	2.8 (-4.9, 10.5)	0.632	0.73	0.76	-0.16	9.8 (9.8)
Flex300R	112.3 \pm 33.1	108.3 \pm 29.8	-4.1 (-13.8, 5.7)	0.280	0.85	0.86	0.13	12.5 (11.0)

Flex300NR	98.0 ± 22.2	100.8 ± 23.4	2.8 (-2.5, 8.0)	0.388	0.91	0.93	-0.13	6.7 (6.6)
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***denotes a significant (p < 0.05) difference between Test A and Test B (between-day). CI = confidence interval; r = Pearson moment correlation coefficient; ICC = intraclass correlation coefficient. TEM = typical error of measurement; CV = coefficient of variation.**

Table 2. Reciprocal vs non-reciprocal peak moment (Nm) for trials at all velocities and modalities. Peak moment values are mean \pm SD

	Reciprocal (Nm)	Non-Reciprocal (Nm)	Mean bias (95% CI)	P	r	ICC	Cohen's d	TEM (CV %)
Ext60	173.6 \pm 32.4	181.9 \pm 36.8	8.2 (0.9, 15.5)	0.03*	0.87	0.88	-0.24	13.9 (7.7)
Ext180	159 \pm 29.7	164.0 \pm 28.0	7.1 (2.3, 11.9)	0.01*	0.90	0.91	-0.18	9.1 (5.9)
Ext300	130.7 \pm 24.2	139.8 \pm 26.5	9.1 (5.1, 13.1)	0.00*	0.91	0.91	-0.36	7.7 (5.1)
Flex60	97.2 \pm 18.0	106.8 \pm 21.4	9.7 (5.2, 14.2)	0.00*	0.83	0.83	-0.49	8.5 (8.5)
Flex180	100.3 \pm 18.1	101.7 \pm 18.7	1.3 (-2.9, 5.5)	0.53	0.81	0.82	-0.08	8.0 (8.3)
Flex300	110.3 \pm 31.0	99.4 \pm 22.4	-10.9 (-18.6, -3.72)	0.00*	0.79	0.76	0.41	13.6 (12.2)

*denotes a significant ($p < 0.05$) difference between the Reciprocal and Non-Reciprocal modalities. CI = confidence interval; r = Pearson moment correlation coefficient; ICC = intraclass correlation coefficient. TEM = typical error of measurement; CV = coefficient of variation.