

1 Variability of multi-angle isometric force-time characteristics in trained men

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3 Running Head: Variability of multi-angle isometric force

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26 **ABSTRACT**

27 Measurements of isometric force, rate of force development (RFD) and impulse are widely  
28 reported. However, little is known about the variability and reliability of these measurements  
29 at multiple angles, over repeated testing occasions in a homogenous, resistance-trained  
30 population. Thus, understanding the intersession variability of multi-angle isometric force-time  
31 characteristics provides the purpose of this paper. Three sessions of isometric knee extensions  
32 at 40°, 70° and 100° of flexion were performed by 26 subjects across 51 limbs. All assessments  
33 were repeated on three occasions separated by 5-8 days. Variability was qualified by doubling  
34 the typical error of measurement (TEM), with thresholds of 0.2-0.6 (small), 0.6-1.2 (moderate),  
35 1.2-2.0 (large), 2.0-4.0 (very large) and >4.0 (extremely large). Additionally, variability was  
36 deemed large when the intraclass correlation coefficient (ICC) was <0.67 and coefficient of  
37 variation (CV)>10%; moderate when ICC>0.67 or CV<10% (but not both); and small when  
38 both ICC>0.67 and CV<10%. Small to moderate between-session variability (ICC=0.68-0.95,  
39 CV=5.2-18.7%, TEM=0.24-0.49) was associated with isometric peak force, regardless of  
40 angle. Moderate to large variability was seen in early-stage (0-50 ms) RFD and impulse  
41 (ICC=0.60-0.80, CV=22.4-63.1%, TEM=0.62-0.74). Impulse and RFD at 0-100 ms, 0-200 ms  
42 and 100-200 ms were moderately variable (ICC=0.71-0.89, CV=11.8-42.1%, TEM=0.38-0.60)  
43 at all joint angles. Isometric peak force and late-stage isometric RFD and impulse  
44 measurements were found to have low intersession variability regardless of joint angle.  
45 However, practitioners need to exercise caution when making inferences about early-stage  
46 RFD and impulse measures due to moderate-large variability.

47

48 **Keywords:** Force; impulse; optimal-angle; rate of force development; reliability

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50

## 51 INTRODUCTION

52 Traditionally, the evaluation of the length-tension relationship has been completed via  
53 isokinetic derived angle of peak torque (i.e. optimal-angle) (23). However, dynamic  
54 contractions do not allow for reliable rate of force development (RFD) metrics. Additionally,  
55 eccentric evaluations require extensive familiarization and may be excessively strenuous if  
56 regular testing is required (23). As such, isometric evaluations of force, RFD and impulse are  
57 popular in general (17), athletic (6, 16), and rehabilitative (1, 5, 10) populations due to the ease  
58 of use and a high degree of safety (25). Additionally, isometric evaluations are regularly  
59 utilized to gain insight regarding neural drive and pain-induced inhibition via the rapid  
60 application of force (13), which is valuable in a variety of contexts (1, 6, 10, 19, 25). For  
61 example, Angelozzi et al. (1) reported that while peak force returned to baseline six-months  
62 after anterior cruciate ligament reconstruction, early-stage (0-30 ms, 0-50 ms, 0-90 ms) RFD  
63 remained measurably depressed 12 months post reconstruction. Furthermore, late-stage (100-  
64 200 ms) RFD is a more sensitive means of indirectly evaluating exercise-induced muscle  
65 damage than peak force, providing value in research settings (19).

66

67 Isometric contractions at multiple joint angles are commonly included in testing  
68 batteries (3, 11, 14) as morphological and functional adaptations to training appear to be joint  
69 angle specific (17). For example, Kubo et al. (11) observed that isometric training at long  
70 muscle lengths resulted in significantly improved isometric force from 40-110° of knee-  
71 flexion, whereas short muscle length training only improved force production from 40-80°.  
72 Thus, no between-group differences would have been detected if force production had been  
73 evaluated at a single joint angle of  $\leq 80^\circ$  (11). Furthermore, strength and rapid force production  
74 at specific joint angles may provide beneficial information to athletic and rehabilitative  
75 populations. For instance, many knee and hamstring injuries occur at, or near, full extension

76 (7), and strength near the end-range of motion is a strong indicator of recovery (4).  
77 Alternatively, high force outputs at long muscle lengths critical to performance for athletes  
78 such as weightlifters (22). Therefore, isometric evaluation of muscle properties should take  
79 place at multiple angles, i.e. whole muscle length-tension relationship (23).

80

81         While multi-angle isometric assessments have the potential to be useful in athletic and  
82 rehabilitation settings, several limitations have been identified by researchers. For example,  
83 nine of 26 papers included in a recent systematic review of isometric resistance training  
84 included multi-angle isometric assessments (17). However, only six reported reliability, and in  
85 three, variability was only derived from a single session (i.e. within-trial variation) (17), which  
86 has limited application to test-retest methodologies. Additionally, each study in the review (17),  
87 and the earlier cited studies do not report their own reliabilities (5, 10, 16, 19), or report only a  
88 single statistic, with a mixture of intraclass coefficient correlation (ICC) (1, 3), or the  
89 coefficient of variation (CV) (11, 14). Moreover, while peak force was highly reliable  
90 (ICC=0.80-0.99) across seven accepted studies, a systematic review of closed-chain isometric  
91 assessments (6) only reported pooled ICCs, which raises some issues. For example, while it is  
92 the most commonly reported reliability statistic, the ICC is overly reliant on between-subject  
93 variability, which minimally affects typical error of measure (TEM) and CVs (8, 20). Another  
94 limitation was the distinct lack of resistance-trained subjects as none of the papers included in  
95 the aforementioned systematic review included subjects with any substantial strength training  
96 history (17). Furthermore, the variability of RFD and impulse are seldom reported (1, 3).  
97 Therefore, the primary purpose of this technical report is to provide a comprehensive analysis  
98 of the variability of a multi-angle isometric knee extension assessment over three testing  
99 sessions in resistance-trained subjects. The findings of this report will provide greater insight

100 into isometric measures that can be used with confidence in test-retest methodologies that are  
101 quantifying longitudinal changes.

102

## 103 **METHODS**

### 104 **Experimental design**

105 Isometric force-time characteristics of the knee extensors were examined using a  
106 repeated measures study design. Subjects were tested on three separate occasions, with 5-8  
107 days between sessions. Each session followed identical sequencing of testing including a series  
108 of isometric contractions at short (40°), medium (70°), and long (100°) muscle lengths (0°=full  
109 extension). Intersession variability of peak force, early (0-50 ms) and late-stage (0-100 ms, 0-  
110 200 ms, 100-200 ms) RFD and impulse were examined via ICC, CV, and TEM.

111

### 112 **Subjects**

113 Twenty-six healthy, resistance-trained males ( $28.8 \pm 4.8$  years,  $180.2 \pm 7.7$  cm,  $81.8 \pm 11.8$   
114 kg) volunteered. To minimize training effects from the testing procedures, all subjects were  
115 required to have at least six months of resistance training experience (21) ( $2.53 \pm 0.76$   
116 sessions $\cdot$ week<sup>-1</sup>), and be free of musculoskeletal injuries in the three months before data  
117 collection. Participants were instructed to maintain their current level of physical activity  
118 throughout the data collection period apart from refraining from strenuous physical activity in  
119 the 72 hours before each session. Additionally, participants were instructed to avoid alcohol,  
120 caffeine, and other ergogenic aids for at least 24 hours before each session. The Auckland  
121 University of Technology Research Ethics Committee approved the study (18/232), and all  
122 subjects gave written informed consent after being informed of the risks and benefits of  
123 participation.

124

## 125 **Testing procedures**

### 126 *Isometric testing*

127 Participants warmed up by cycling at a low to moderate resistance using a self-selected  
128 pace for five minutes. Participants were seated upright on the isokinetic dynamometer (CSMi;  
129 Lumex, Ronkonkoma, NY, USA) at a hip angle of 85°, with shoulder, waist and thigh straps to  
130 reduce body movement during contractions. The shin-pad force was ~5 cm superior to the  
131 medial malleoli. Participants were required to hold the handles at the sides of the chair, and the  
132 non-working limb was positioned behind a restraining pad. Knee alignment was determined by  
133 visual inspection and unloaded knee extensions to ensure proper joint tracking. Dynamometer  
134 settings were recorded and matched for all subsequent sessions.

135

136 Once fitted to the dynamometer, participants underwent a series of extensions and  
137 flexions of the knee to determine the safety stop positions and calibrate to the gravity  
138 correction. Participants then completed a standardized warmup of submaximal concentric  
139 contractions of 30%, 50%, 70%, 85% and 100% of perceived maximal voluntary contraction.  
140 Each warm-up contraction was initiated and terminated at 105° and 5° of knee flexion,  
141 respectively. Sixty seconds after the completion of the isokinetic warm-up, the participants'  
142 knee was positioned at 40° of flexion where one familiarization isometric knee extension at  
143 50% of maximal voluntary isometric contraction (MVIC) was performed. Subsequently, two  
144 MVICs lasting four seconds were completed with 30 seconds separating each contraction.  
145 Participants were instructed to contract “as fast and hard as possible” following a countdown  
146 of “3-2-1-go!” (13). All athletes were given strong verbal encouragement along with visual  
147 feedback of the force-time tracing during each trial (13). Participants were also instructed to  
148 avoid any pre-tension and countermovement of the knee extensors while the live force-time  
149 trace was carefully inspected by the examiner leading up to each contraction (13). The cut-off

150 for pre-tension was set at 10 N. Any contractions with a clear countermovement or an unsteady  
151 baseline were rejected and repeated (13). The subjects then completed the same series at 70°  
152 and 100° of knee flexion with 60 seconds of rest between angles. The isometric contractions  
153 were always performed in series from short to long muscle lengths to avoid greater muscle  
154 damage and fatigue synonymous with contractions at long muscle lengths (14). Following the  
155 final isometric contraction, the isokinetic warm-up and isometric assessment were repeated on  
156 the opposite limb. Limb order was randomized throughout the three testing sessions and  
157 counterbalanced over the sample. All isokinetic and isometric contractions were collected,  
158 without filtering, via a custom-made software (LabVIEW; National Instruments, New Zealand)  
159 sampling at 2000 Hz (13).

160

#### 161 *Data processing and analysis*

162 Data were analyzed via a customized MATLAB (MathWorks, Natick, MA) script. All  
163 dynamometer data was divided by the length of the lever arm, in meters, to normalize the  
164 difference in shank length between subjects. Following an initial manual inspection of the raw  
165 data, isometric forces over 200 N were identified to signify a full contraction and eliminate  
166 false contractions. A peak detection algorithm was implemented to detect and identify the  
167 instantaneous peak force of each contraction. The on-set of effort was determined via visual  
168 inspection and a manual section of each force-time curve (13). The same researcher determined  
169 on-set of effort by visually detecting the last trough before force deflected above the range of  
170 the baseline noise (13). Rate of force development and impulse were calculated for 0-50 ms,  
171 0-100 ms, 0-200 ms, and 100-200 ms, based on the manual onset of effort detection (13).

172

#### 173 **Statistical analysis**

174 Mean, and standard deviation was calculated for all variables. All data were log-  
175 transformed to correct for heteroscedastic effects and analyzed using an Excel (version 2016;  
176 Microsoft Corporation, Redmond, WA) spreadsheet (8, 15). Intersession analysis was  
177 performed on the mean results of the variables for each session. The ICC and CV were used to  
178 explore relative and absolute variability respectively. An  $ICC < 0.67$  and  $CV > 10\%$  were deemed  
179 as having large variability, moderate variability when either the  $ICC > 0.67$  or the  $CV < 10\%$ , but  
180 not both, and small variability when  $ICC > 0.67$  and  $CV < 10\%$  (12, 15). Variability was also  
181 examined via TEM to provide the reader with a practical interpretation of the magnitude of  
182 error expected for any change in the mean (12, 15). Magnitudes for effects were calculated by  
183 doubling the TEM result (12, 15) with thresholds of 0.2-0.6 (small), 0.6-1.2 (moderate), 1.2-  
184 2.0 (large), 2.0-4.0 (very large) and  $>4.0$  (extremely large) (9, 12, 15).

185

## 186 **RESULTS**

187 Variability data for multi-angle isometric force, RFD and impulse measures are found  
188 in Table 1.

189

190 (Table 1. About here)

191

192 Small to moderate variabilities were found for isometric peak force ( $ICC=0.80-0.93$ ,  
193  $CV=6.7-11.5\%$ ,  $TEM=0.28-0.49$ ) while late-stage (0-100, 100-200, 0-200 ms) RFD  
194 ( $ICC=0.67-0.88$ ,  $CV=10.4-21.5\%$ ,  $TEM=0.37-0.74$ ) and impulse ( $ICC=0.77-0.89$ ,  $CV=21.5-$   
195  $42.1\%$ ,  $TEM=0.36-0.56$ ) were moderately variable regardless of angle between sessions one-  
196 two and two-three. However, moderate to large variability were found for early-stage (0-50  
197 ms) RFD ( $ICC=0.60-0.71$ ,  $CV=22.4-33.7\%$ ,  $TEM=0.64-0.82$ ) and impulse ( $ICC=0.68-0.80$ ,  
198  $CV=32.9-63.1\%$ ,  $TEM=0.51-0.70$ ).



199

200 **DISCUSSION**

201 A comprehensive analysis of the variability associated with isometric peak force, RFD  
202 and impulse at multiple angles during knee extension, in a homogenous resistance-trained  
203 population was previously lacking. This study addressed these limitations with the primary  
204 findings being: 1) peak force is minimally variable, 2) late-stage RFD and impulse are  
205 moderately variable, and 3) early-stage RFD and impulse hold moderate to large variability.

206

207 Small to moderate variability (ICC=0.80-0.93, CV=6.7-11.5%, TEM=0.28-0.49) was  
208 associated with isometric peak force regardless of joint angle, meaning that practitioners and  
209 researchers can be confident in using this metric across angles. Our findings corroborate  
210 previous reports, in that late (ICC=0.67-0.89, CV=10.4-42.1%, TEM=0.36-0.74), but not early-  
211 stage (ICC=0.60-0.80, CV=22.4-63.1%, TEM=0.51-0.82) RFD and impulse, are relatively  
212 stable between testing occasions regardless of joint angle (13, 18). For example, Palmer,  
213 Pineda, and Durham recently reported highly reliable peak force (ICC=0.84-0.90, CV=6.6-  
214 12%) and late-stage RFD (ICC=0.81, CV=12.3-19.4%), while peak and early-stage RFD  
215 (ICC=0.55-0.85, CV=17.3-55.9%) were much less consistent across two sessions in a multi-  
216 angle isometric squat (18). No systematic bias was observed between sessions one-two,  
217 indicating a negligible learning effect and that the assessments need very little familiarisation  
218 in trained subjects.

219

220 From the findings of this technical report, reporting early-stage RFD (1, 19) would seem  
221 questionable, supporting the decisions of researchers who have declined to include rapid force  
222 production earlier than a 100 ms threshold (3). However, it is important to note that large  
223 intersession variability does not necessarily preclude early-stage RFD or impulse from holding

224 value if the smallest detectable change is known. For example, Krafft (10) and Angelozzi (1),  
225 reported relatively large improvements in peak (98.4-103.6%, Cohen's  $d=0.58-1.06$ ) and early-  
226 stage RFD (20.3-41.7%,  $d=0.35-0.44$ ) throughout recovery from anterior cruciate ligament  
227 reconstruction, which may have surpassed the smallest detectable change. However, neither  
228 study reported the information required to calculate the smallest detectable change in their  
229 population. Alternatively, well-trained athletic populations are unlikely to experience large  
230 enough improvements in early-stage RFD and impulse to overcome the moderate to large  
231 intersession variability (21).

232

233 While the primary aim of this report was achieved, readers should be cognizant of the  
234 limitations. All contractions were performed in a commercial dynamometer, where  
235 deformation of the seat and tissues of the subject may result in small shifts in the prescribed  
236 joint angle when compared to custom-made apparatus (2, 13). While the slight deviation in  
237 joint angle should not affect intersession variability, practitioners should be aware that the  
238 reported force, RFD and impulse data may not be interchangeable with other equipment set-  
239 ups (2, 13). Future research should examine other movements (e.g. knee flexion, dorsiflexion)  
240 and populations (e.g. females, elderly, untrained, rehabilitative) to have a full understanding of  
241 the utility and reproducibility of multi-angle isometric force-time characteristics. Finally, while  
242 precedence exists for the specific statistical inference cut-offs in this article (12, 15), it is  
243 important to note that universal consensus is not possible (20, 24). Therefore, readers may wish  
244 to apply their own inferences based on their specific contexts.

245

## 246 **PRACTICAL APPLICATIONS**

247 This was the first study to undertake a comprehensive analysis of knee extension force-  
248 time variability across multiple joint angles and testing occasions. Peak force, and late-stage

249 RFD and impulse were the most stable measures at all assessed angles, indicating that the  
250 whole muscle length-tension relationship can be determined for knee extension. However,  
251 practitioners should avoid reporting early-stage (0-50 ms) RFD and impulse, due to moderate  
252 to large intersession variability. Additionally, practitioners should be aware that outcome  
253 measures with moderate to large variability require larger training-induced adaptations before  
254 they can be sure that real changes have occurred. It also appears that there is minimal learning  
255 involved with the testing, so familiarisation and assessment can occur in the same session with  
256 well-trained individuals. Readers may wish to calculate the smallest worthwhile change from  
257 table 1; however, it is critical to realize that these data are only applicable to a resistance-trained  
258 male population. In summation, isometric peak force, and late-stage RFD and impulse have  
259 low to moderate variability regardless of joint angle and therefore, can be used with confidence  
260 to demonstrate the force capability of knee extensors.

261

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**Table 1.** Test-retest variability of isometric knee extension force production over three repeated measures.

Joint angle	Mean			Days 1 – 2					Days 2 - 3						
	Day 1	Day 2	Day 3	TEM	TEM × 2	TEM inference	CV	ICC	CV/ICC inference	TEM	TEM × 2	TEM inference	CV	ICC	CV/ICC inference
	<b>Peak Force (N)</b>														
40°	611.5 ± 140	601.3 ± 134	603.6 ± 133	0.45	0.90	moderate	10.8	0.84	moderate	0.39	0.78	moderate	9.6	0.87	small
70°	790 ± 201	807.2 ± 174	805.5 ± 188	0.36	0.72	moderate	9.2	0.88	small	0.49	0.98	moderate	11.5	0.80	moderate
100°	669 ± 151	679.2 ± 153	682.7 ± 149	0.28	0.56	small	6.7	0.93	small	0.38	0.76	moderate	8.5	0.88	small
<b>Mean</b>				<b>0.36</b>	<b>0.62</b>	<b>moderate</b>	<b>8.9</b>	<b>0.88</b>	<b>small</b>	<b>0.42</b>	<b>0.84</b>	<b>moderate</b>	<b>9.9</b>	<b>0.85</b>	<b>small</b>
	<b>RFD 0-50 (N·s<sup>-1</sup>)</b>														
40°	3894 ± 1227	3739 ± 967	3635 ± 1053	0.64	1.28	large	22.4	0.71	moderate	0.82	1.64	large	23.5	0.60	large
70°	3245 ± 1255	3003 ± 1304	2940 ± 1121	0.74	1.48	large	32.2	0.66	large	0.66	1.32	large	27.2	0.70	moderate
100°	1690 ± 998	1577 ± 827	1670 ± 1024	0.67	1.34	large	31.9	0.70	moderate	0.70	1.40	large	33.7	0.68	moderate
<b>Mean</b>				<b>0.68</b>	<b>1.36</b>	<b>large</b>	<b>28.8</b>	<b>0.69</b>	<b>moderate</b>	<b>0.73</b>	<b>1.46</b>	<b>large</b>	<b>28.1</b>	<b>0.66</b>	<b>large</b>
	<b>RFD 0-100 (N·s<sup>-1</sup>)</b>														
40°	3401 ± 980	3179 ± 846.8	3142 ± 868	0.57	1.14	moderate	18.7	0.76	moderate	0.60	1.20	moderate	19.9	0.71	moderate
70°	3264 ± 1061	3025 ± 1006.5	2977 ± 939	0.48	0.96	moderate	18.8	0.82	moderate	0.57	1.14	moderate	20.1	0.76	moderate
100°	2334 ± 761	2258 ± 471.6	2293 ± 830	0.51	1.02	moderate	19.4	0.80	moderate	0.57	1.14	moderate	21.7	0.76	moderate
<b>Mean</b>				<b>0.52</b>	<b>1.04</b>	<b>moderate</b>	<b>19</b>	<b>0.79</b>	<b>moderate</b>	<b>0.58</b>	<b>1.16</b>	<b>moderate</b>	<b>20.6</b>	<b>0.74</b>	<b>moderate</b>
	<b>RFD 0-200 (N·s<sup>-1</sup>)</b>														
40°	2459 ± 631	2340 ± 607.7	2297 ± 611	0.55	1.10	moderate	15.9	0.78	moderate	0.53	1.06	moderate	15.6	0.79	moderate
70°	2804 ± 790	2643 ± 755.3	2618 ± 728	0.43	0.86	moderate	14	0.85	moderate	0.47	0.94	moderate	14.9	0.82	moderate
100°	2271 ± 575	2224 ± 584	2266 ± 637	0.39	0.78	moderate	11.8	0.87	moderate	0.43	0.86	moderate	13	0.85	moderate
<b>Mean</b>				<b>0.46</b>	<b>0.92</b>	<b>moderate</b>	<b>13.9</b>	<b>0.83</b>	<b>moderate</b>	<b>0.48</b>	<b>0.96</b>	<b>moderate</b>	<b>14.5</b>	<b>0.82</b>	<b>moderate</b>
	<b>RFD 100-200 (N·s<sup>-1</sup>)</b>														
40°	1534 ± 460	1501 ± 446.6	1452 ± 459	0.74	1.48	large	21.5	0.67	moderate	0.53	1.06	moderate	17.1	0.79	moderate
70°	2344 ± 649	2261 ± 634.6	2259 ± 637	0.45	0.90	moderate	13.9	0.84	moderate	0.46	0.92	moderate	15	0.83	moderate
100°	2207 ± 560	2190 ± 557.1	2240 ± 558	0.39	0.78	moderate	10.9	0.87	moderate	0.37	0.74	moderate	10.4	0.88	moderate
<b>Mean</b>				<b>0.53</b>	<b>1.06</b>	<b>moderate</b>	<b>15.4</b>	<b>0.79</b>	<b>moderate</b>	<b>0.45</b>	<b>0.90</b>	<b>moderate</b>	<b>14.2</b>	<b>0.83</b>	<b>moderate</b>
	<b>Impulse 0-50 (N·s)</b>														
40°	10.6 ± 5.7	9.38 ± 4.3	9.19 ± 4.6	0.51	1.02	moderate	32.9	0.80	moderate	0.57	1.14	moderate	32.9	0.76	moderate
70°	8.15 ± 6	7.26 ± 5.8	6.8 ± 4.4	0.70	1.40	large	56.2	0.68	moderate	0.57	1.14	moderate	42.5	0.76	moderate
100°	2.93 ± 3.5	2.52 ± 2.6	2.86 ± 3.6	0.66	1.32	large	61	0.70	moderate	0.70	1.40	large	63.1	0.68	moderate
<b>Mean</b>				<b>0.62</b>	<b>1.24</b>	<b>large</b>	<b>50</b>	<b>0.73</b>	<b>moderate</b>	<b>0.61</b>	<b>1.22</b>	<b>large</b>	<b>46.2</b>	<b>0.73</b>	<b>moderate</b>
	<b>Impulse 0-100 (N·s)</b>														
40°	21.9 ± 10.6	27.3 ± 12.3	16.8 ± 12.9	0.52	1.04	moderate	36.3	0.79	moderate	0.52	1.04	moderate	33.1	0.79	moderate

70°	30.8 ± 17.4	26.7 ± 15.6	25.7 ± 14	0.43	0.86	moderate	33.8	0.85	moderate	0.52	1.04	moderate	37	0.80	moderate
100°	16.8 ± 9.2	15.7 ± 8.7	16.5 ± 10.6	0.49	0.98	moderate	38.4	0.81	moderate	0.53	1.06	moderate	42.1	0.79	moderate
<b>Mean</b>				<b>0.48</b>	<b>0.96</b>	<b>moderate</b>	<b>36.2</b>	<b>0.82</b>	<b>moderate</b>	<b>0.52</b>	<b>1.04</b>	<b>moderate</b>	<b>37.4</b>	<b>0.79</b>	<b>moderate</b>
<b>Impulse 0-200 (N·s)</b>															
40°	64.5 ± 28.7	58.7 ± 26.6	57 ± 27.1	0.51	1.02	moderate	30.7	0.80	moderate	0.44	0.88	moderate	27	0.85	moderate
70°	87.4 ± 43.9	78.1 ± 39.4	76.4 ± 38.9	0.41	0.82	moderate	27.6	0.86	moderate	0.45	0.90	moderate	29.6	0.84	moderate
100°	58.2 ± 26.1	56.2 ± 25.4	58.7 ± 30.7	0.38	0.76	moderate	23.6	0.88	moderate	0.41	0.82	moderate	25.9	0.86	moderate
<b>Mean</b>				<b>0.43</b>	<b>0.86</b>	<b>moderate</b>	<b>27.3</b>	<b>0.85</b>	<b>moderate</b>	<b>0.43</b>	<b>0.86</b>	<b>moderate</b>	<b>27.5</b>	<b>0.85</b>	<b>moderate</b>
<b>Impulse 100-200 (N·s)</b>															
40°	33.9 ± 15.9	31.4 ± 15.2	30.3 ± 15.1	0.56	1.12	moderate	33.1	0.77	moderate	0.41	0.82	moderate	25.8	0.86	moderate
70°	56.5 ± 27.9	51.3 ± 25	50.6 ± 24.9	0.41	0.82	moderate	26.9	0.86	moderate	0.44	0.88	moderate	29.2	0.84	moderate
100°	41.4 ± 18.5	40.4 ± 17.8	42.2 ± 21	0.36	0.72	moderate	21.5	0.89	moderate	0.38	0.76	moderate	23.1	0.88	moderate
<b>Mean</b>				<b>0.44</b>	<b>0.88</b>	<b>moderate</b>	<b>27.2</b>	<b>0.84</b>	<b>moderate</b>	<b>0.41</b>	<b>0.82</b>	<b>moderate</b>	<b>26</b>	<b>0.86</b>	<b>moderate</b>

TEM = typical error of measure. CV = coefficient of variation (%). ICC = intraclass correlation coefficient. RFD = rate of force development. N·s<sup>-1</sup> = Newtons per second. N·s = Newton seconds. All reliability statistics are log-transformed.