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

Running Head: Variability of multi-angle isometric force

Authors: *Dustin J. Oranchuk[1], Adam G. Storey[1], André R. Nelson[2], Jonathon G. Neville[1], John B. Cronin[1]

1. Sports Performance Research Institute New Zealand, Auckland University of Technology, Auckland, New Zealand
2. Institute for Health and Sport, Victoria University, Melbourne, Australia

*Corresponding author: Dustin J. Oranchuk

+64 027 800 8555
AUT-Millennium, 17 Antares Place, Mairangi Bay
Auckland, New Zealand
dustinoranchuk@gmail.com

Figures: 0

Tables: 1

Funding Disclosure: None

Conflict of Interest: None

ABSTRACT

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

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

INTRODUCTION

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

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

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

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

METHODS

Experimental design

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

Subjects

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

Testing procedures

Isometric testing

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

Once fitted to the dynamometer, participants underwent a series of extensions and flexions of the knee to determine the safety stop positions and calibrate to the gravity correction. Participants then completed a standardized warmup of submaximal concentric contractions of 30%, 50%, 70%, 85% and 100% of perceived maximal voluntary contraction. Each warm-up contraction was initiated and terminated at 105° and 5° of knee flexion, respectively. Sixty seconds after the completion of the isokinetic warm-up, the participants' knee was positioned at 40º of flexion where one familiarization isometric knee extension at 50% of maximal voluntary isometric contraction (MVIC) was performed. Subsequently, two MVICs lasting four seconds were completed with 30 seconds separating each contraction. Participants were instructed to contract “as fast and hard as possible” following a countdown of “3-2-1-go!” (13). All athletes were given strong verbal encouragement along with visual feedback of the force-time tracing during each trial (13). Participants were also instructed to avoid any pre-tension and countermovement of the knee extensors while the live force-time trace was carefully inspected by the examiner leading up to each contraction (13). The cut-off for pre-tension was set at 10 N. Any contractions with a clear countermovement or an unsteady baseline were rejected and repeated (13). The subjects then completed the same series at 70º and 100º of knee flexion with 60 seconds of rest between angles. The isometric contractions were always performed in series from short to long muscle lengths to avoid greater muscle damage and fatigue synonymous with contractions at long muscle lengths (14). Following the final isometric contraction, the isokinetic warm-up and isometric assessment were repeated on the opposite limb. Limb order was randomized throughout the three testing sessions and counterbalanced over the sample. All isokinetic and isometric contractions were collected, without filtering, via a custom-made software (LabVIEW; National Instruments, New Zealand) sampling at 2000 Hz (13).

Data processing and analysis

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

Statistical analysis

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

RESULTS

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

(Table 1. About here)

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

DISCUSSION

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

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

From the findings of this technical report, reporting early-stage RFD (1, 19) would seem questionable, supporting the decisions of researchers who have declined to include rapid force production earlier than a 100 ms threshold (3). However, it is important to note that large intersession variability does not necessarily preclude early-stage RFD or impulse from holding value if the smallest detectable change is known. For example, Krafft (10) and Angelozzi (1), reported relatively large improvements in peak (98.4-103.6%, Cohen's *d*=0.58-1.06) and early-stage RFD (20.3-41.7%, *d*=0.35-0.44) throughout recovery from anterior cruciate ligament reconstruction, which may have surpassed the smallest detectable change. However, neither study reported the information required to calculate the smallest detectable change in their population. Alternatively, well-trained athletic populations are unlikely to experience large enough improvements in early-stage RFD and impulse to overcome the moderate to large intersession variability (21).

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

PRACTICAL APPLICATIONS

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

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

REFERENCES

1. Angelozzi M, Madama M, Corsica C, Calvisi V, Properzi G, McCaw ST, and Cacchio A. Rate of force development as an adjunctive outcome measure for return-to-sport decisions after anterior cruciate ligament reconstruction. *J Orthop Sports Phys Ther* 42: 772-780, 2012.
2. Arampatzis A, Karamanidis K, De Monte G, Stafilidis S, Morey-Klapsing G, and Büggemann P. Differences between measured and resultant joint moments during voluntary and artificially elicited isometric knee extension contractions. *Clin Biomech* 19: 277-283, 2004.
3. Bogdanis GC, Tsoukos A, Methenitis SK, Selima E, Veligekas P, and Terzis G. Effects of low volume isometric leg press complex training at two knee angles on force-angle relationship and rate of force development. *Eur J Sport Sci* 19: 345-353, 2018.
4. Cavanaugh JT and Powers M. ACL rehabilitation progression: Where are we now? *Curr Rev Musculoskelet Med* 10: 289-296, 2017.
5. Cichanowski HR, Schmitt JS, Johnson RJ, and Niemuth PE. Hip strength in collegiate female athletes with patellofemoral pain. *Med Sci Sports Exerc* 39: 1227-1232, 2007.
6. Drake D, Kennedy R, and Wallace E. The validity and responsiveness of isometric lower body multi-joint tests of muscular strength: A systematic review. *Sports Med Open* 3: 1-11, 2017.
7. Escamilla RF, Macleod TD, Wilk KE, Paulos L, and Andrews JR. Anterior cruciate ligament strain and tensile forces for weight-bearing and non-weight-bearing exercises: a guide to exercise selection. *J Orthop Sports Phys Ther* 42: 208-220, 2012.

8. Hopkins WG. Measures of reliability in sports medicine and science. *Sports Med* 30: 1-15, 2000.
9. Hopkins WG, Marshall SW, Batterham AM, and Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc* 41: 2009, 2009.
10. Krafft FC, Sterrer BJ, Stein T, Ellermann A, Flechtenmarcher J, Eberle C, Sell S, and Potthast W. How does functionality proceed in ACL reconstructed subjects? Proceeding of functional performance from pre- to six months post-ACL reconstruction. *PLoS One* 12: e0178430, 2017.
11. Kubo K, Ohgo K, Takeishi R, Yoshinaga K, Tsunoda N, Kanehisa H, and Fukunaga T. Effects of isometric training at different knee angles on the muscle–tendon complex in vivo. *Scand J Med Sci Sports* 16: 159-167, 2006.
12. Lenetsky S, Brughelli M, Nates RJ, Cross MR, and Lormier AV. Validity and reliability of punching impact kinetics in untrained participants and experienced boxers. *J Strength Cond Res* 32: 1838-1842, 2018.
13. Maffiuletti NA, Aagaard P, Blazevich AJ, Folland J, Tillin N, and Duchateau J. Rate of force development: Physiological and methodological considerations. *Eur J Appl Physiol* 116: 1091-1116, 2016.
14. Noorkoiv M, Nosaka K, and Blazevich AJ. Neuromuscular adaptations associated with knee joint angle-specific force change. *Med Sci Sports Exerc* 46: 1525-1537, 2014.
15. Oranchuk DJ, Nelson AR, Storey AG, and Cronin JB. Variability of regional quadriceps architecture in trained men assessed by B-mode and extended-field-of-view ultrasonography. *Int J Sports Physiol Perform* Ahead of print, 2019.
16. Oranchuk DJ, Robinson TL, Switaj ZJ, and Drinkwater EJ. Comparison of the hang high-pull and loaded jump squat for the development of vertical jump and isometric force-time characteristics. *J Strength Cond Res* 33: 17-24, 2019.
17. Oranchuk DJ, Storey AG, Nelson AR, and Cronin JB. Isometric training and long-term adaptations; effects of muscle length, intensity and intent: A systematic review. *Scand J Med Sci Sports* 29: 484-503, 2019.
18. Palmer TB, Pineda JG, and Durham RM. Effects of knee position on the reliability and production of maximal and rapid strength characteristics during an isometric squat test. *J Appl Biomech* 34: 111-117, 2018.
19. Penailillo L, Blazevich A, Numazawa H, and Nosaka K. Rate of force development as a measure of muscle damage. *Scand J Med Sci Sports* 25: 417-427, 2015.
20. Prescott RJ. Editorial: Avoid being tripped up by statistics: Statistical guidance for a successful research paper. *Gait Posture* 72: 240-249, 2019.
21. Ratamess NA, Alvar BA, Evetoch TK, Housh TJ, Kibler WB, Kraemer WJ, and Triplett NT. American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. *Med Sci Sports Exerc* 41: 687-708, 2009.
22. Storey A and Smith HK. Unique aspects of competitive weightlifting: Performance, training and physiology. *Sports Med* 42: 769-790, 2012.
23. Timmins RG, Shield AJ, Williams MD, and Opar DA. Is there evidence to support the use of the angle of peak torque as a marker of hamstrings injury and re-injury risk. *Sports Med* 46: 7-13, 2015.
24. Weir JP. Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. *J Strength Cond Res* 19: 231-240, 2005.
25. Wilson GJ and Murphy AJ. The use of isometric tests of muscular function in athletic assessment. *Sports Med* 22: 19-37, 1996.

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

	Mean			**Days 1 – 2**						**Days 2 - 3**					
Joint angle	**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**
Peak Force (N)															
40º	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
70º	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
100º	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
Mean				**0.36**	**0.62**	**moderate**	**8.9**	**0.88**	**small**	**0.42**	**0.84**	**moderate**	**9.9**	**0.85**	**small**
RFD 0-50 (N·s^{-1})															
40º	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
70º	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
100º	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
Mean				**0.68**	**1.36**	**large**	**28.8**	**0.69**	**moderate**	**0.73**	**1.46**	**large**	**28.1**	**0.66**	**large**
RFD 0-100 (N·s^{-1})															
40º	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
70º	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
100º	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
Mean				**0.52**	**1.04**	**moderate**	**19**	**0.79**	**moderate**	**0.58**	**1.16**	**moderate**	**20.6**	**0.74**	**moderate**
RFD 0-200 (N·s^{-1})															
40º	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
70º	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
100º	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
Mean				**0.46**	**0.92**	**moderate**	**13.9**	**0.83**	**moderate**	**0.48**	**0.96**	**moderate**	**14.5**	**0.82**	**moderate**
RFD 100-200 (N·s^{-1})															
40º	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
70º	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
100º	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
Mean				**0.53**	**1.06**	**moderate**	**15.4**	**0.79**	**moderate**	**0.45**	**0.90**	**moderate**	**14.2**	**0.83**	**moderate**
Impulse 0-50 (N·s)															
40º	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
70º	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
100º	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
Mean				**0.62**	**1.24**	**large**	**50**	**0.73**	**moderate**	**0.61**	**1.22**	**large**	**46.2**	**0.73**	**moderate**
Impulse 0-100 (N·s)															
40º	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

70º	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
100º	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
Mean				**0.48**	**0.96**	**moderate**	**36.2**	**0.82**	**moderate**	**0.52**	**1.04**	**moderate**	**37.4**	**0.79**	**moderate**
Impulse 0-200 (N·s)															
40º	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
70º	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
100º	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
Mean				**0.43**	**0.86**	**moderate**	**27.3**	**0.85**	**moderate**	**0.43**	**0.86**	**moderate**	**27.5**	**0.85**	**moderate**
Impulse 100-200 (N·s)															
40º	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
70º	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
100º	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
Mean				**0.44**	**0.88**	**moderate**	**27.2**	**0.84**	**moderate**	**0.41**	**0.82**	**moderate**	**26**	**0.86**	**moderate**

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