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

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

Keywords: Isokinetic, peak moment, quadriceps, hamstrings, muscular assessment

Introduction

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

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

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

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

Material and Method

Participants

Fifteen resistance-trained, male participants were recruited (age = 23.2 ± 3.7 years, stature = 179 ± 6 cm, body mass = 79.3 ± 9.4 kg). Participants had never previously performed a strength assessment using isokinetic dynamometry. Participants were uninjured, had not previously sustained injury to the thigh or knee, and were undertaking moderate to vigorous physical activity of >30 minutes in duration at least five times per week, with at least one of those sessions being resistance training. All participants completed a medical questionnaire and were provided with an information sheet about the research. Verbal information was given to each subject on the assessment day to finalise the informed consent procedure. Participants signed a declaration to confirm they consented to testing and could withdraw at any time. Approval for the study was granted by the University's ethics committee in accordance with the Declaration of Helsinki.

Experimental Procedure

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

The main protocol consisted of three blocks of three sets of five repetitions and is shown in Figure 1. One set comprised either: 5 maximal active flexions followed by passive extensions (non-reciprocal); or 5 maximal active extension and flexion (reciprocal); or 5 maximal active extensions followed by passive flexions (non-reciprocal). Passive movements in the non-reciprocal assessment modality were performed at 60°·s^{-1}. Each set was interspersed with 60 seconds rest. Upon completion of each set, the participant was afforded a five-minute rest period whilst the velocity of movement was altered. The order of movement velocity was 180°·s^{-1}, 300°·s^{-1}, and 60°·s^{-1}. This was used to minimise any order effect owing to a perception of accommodation and increased importance of latter trials if a progressive velocity pattern was followed (Greig, 2008).

[Figure 1 here]

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

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

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

Data and Statistical Analysis

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

A mixed-model, repeated measures ANOVA was selected to analyse the data using SPSS (SPSS Inc., v.24.0, Chicago, IL, USA). Significant interactions were further investigated with paired samples t-tests. Graphs were produced in Microsoft Excel (Microsoft Office 2010, Microsoft, Seattle, USA) Statistical significance was set at an alpha level of $P<0.05$.

Results

(TABLE 1 HERE)

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

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

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

respectively). A medium negative effect was observed for flexion trials at 60°·s^{-1} (= -0.5)

(FIGURE 2 HERE)

Discussion

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

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

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

Obtaining accurate peak moment data is critical as it is often used to form a strength ratio between the knee extensors and flexors. The quadriceps/hamstrings strength ratio has long been purported to be an indicator of susceptibility to injury, although the exact mechanisms are not well understood and remain controversial (Croisier et al., 2008). Andrade et al. (2012) suggest that in injured or recreational participants, utilising slower angular velocities should result in increased reliability. The data presented in the Andrade paper agrees with this report that as angular velocity increases, the strength ratio widens (more contribution from the extensors). The increased contribution from the quadriceps to distort the ratio at high angular velocities has been demonstrated to occur in male and female athletes, from a range of backgrounds, up to $180°\cdot s^{-1}$ (Rosene, Fogarty, & Mahaffey, 2001). The present study demonstrates that if utilising high velocity movements using non-reciprocal methods, the increased moment from the knee extensors, and the reduced moment from the knee flexors (in comparison to reciprocal methods) will likely distort this ratio. Therefore, it is suggested that practitioners using isokinetic dynamometry to interpret muscular strength data carefully consider the protocol adopted to provide the most functionally relevant and reliable assessment.

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

Conclusion:

Practitioners utilising isokinetic dynamometry for assessment of strength should ensure that their data collection methods are robust. The data presented herein suggest that, in resistance-trained participants, using non-reciprocal actions will result in higher peak moment, expect for the knee flexors at high velocity. Reciprocal actions show reliability between days, as do non-reciprocal trials. However, the peak moments obtained using reciprocal and non-reciprocal methods are often significantly different. Therefore, the accurate and consistent reporting of which modality is utilised is encouraged to allow readers to better understand the results obtained. Further research is required in other populations to ascertain whether reciprocal or non-reciprocal assessment methods yield more reliable measures and therefore provide more accurate estimation of injury potential.

Conflict of Interest Statement

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

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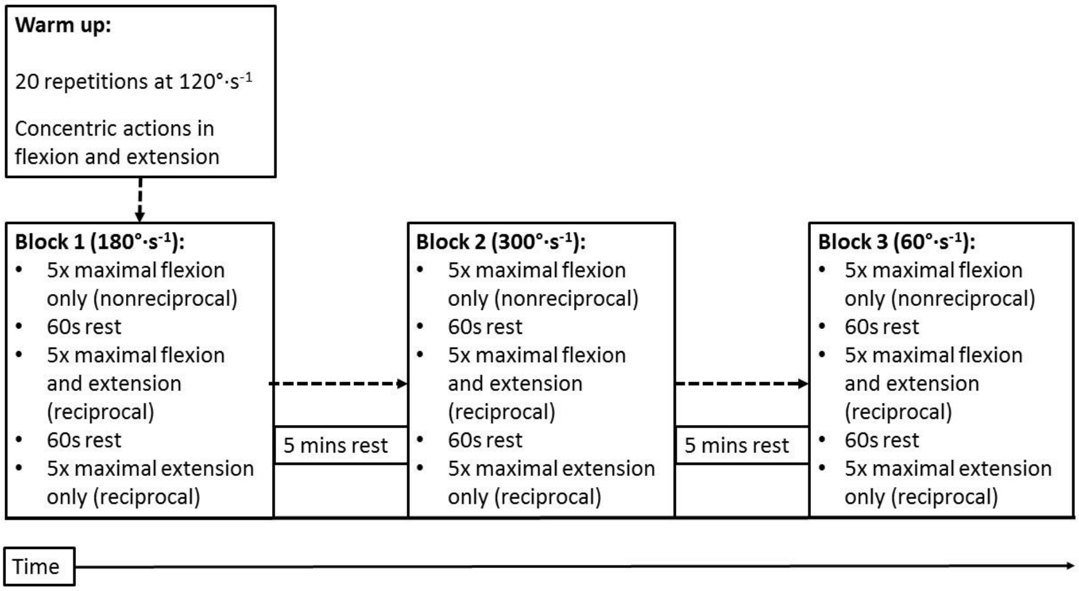

Figure 1: Protocol design schematic

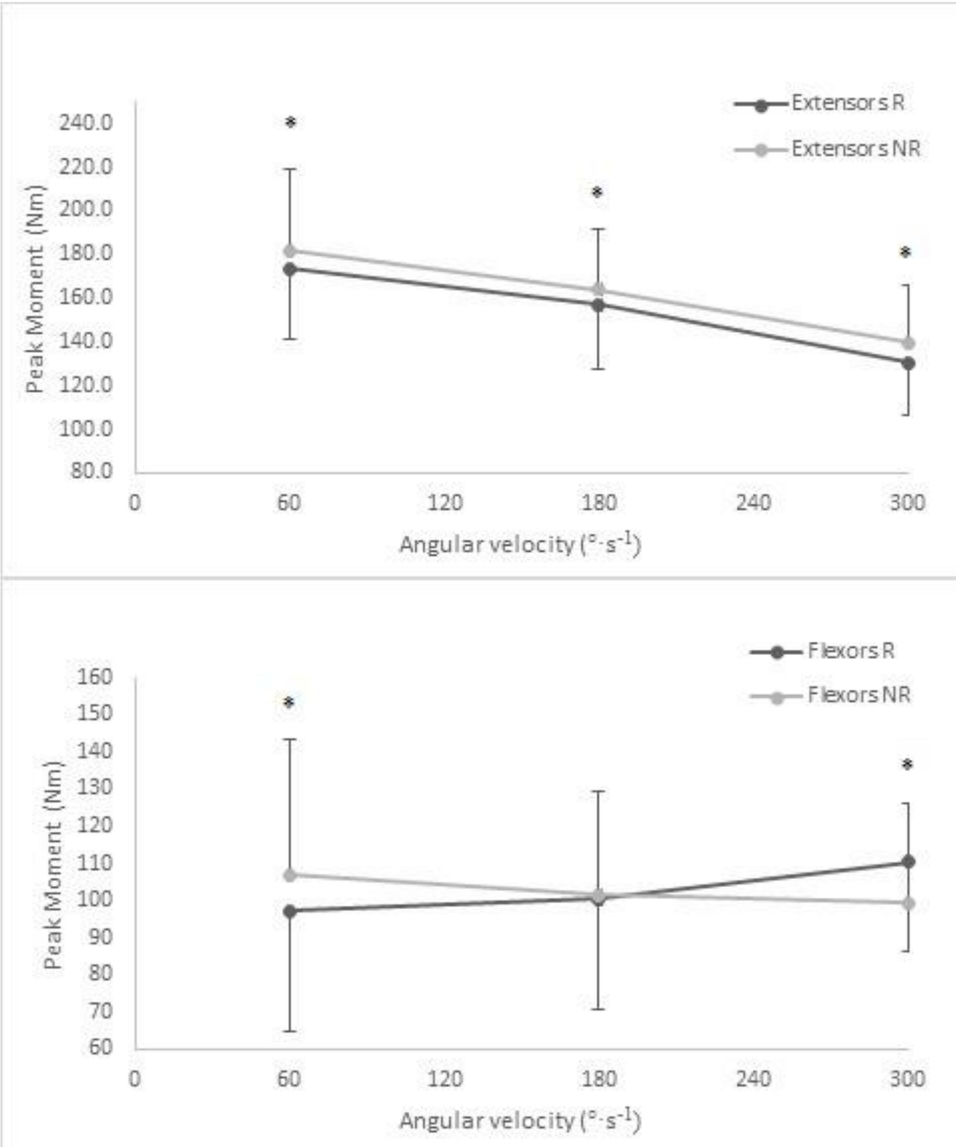

Figure 2: Peak moment (Nm) for extensors (top) and flexors (bottom) during reciprocal and nonreciprocal modalities. Error bars represent SD. * = p < .05.

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

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

***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 ± SD

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