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Reliability of knee extension and flexion measurements using the Con-Trex isokinetic dynamometer

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Summary

The aim of this study was to evaluate the reliability of isokinetic and isometric assessments of the knee extensor and the flexor muscle function using the Con-Trex isokinetic dynamometer. Thirty healthy subjects (15 males, 15 females) were tested and retested 7 days later for maximal strength (isokinetic peak torque, work, power and angle of peak torque as well as isometric maximal voluntary contraction torque and rate of torque development) and fatigue (per cent loss and linear slope of torque and work across a series of 20 contractions). For both the knee extensor and the flexor muscle groups, all strength data – except angle of peak torque – demonstrated moderate-to-high reliability, with intraclass correlation coefficients (ICC) higher than 0·86. The highest reliability was observed for concentric peak torque of the knee extensor muscles (ICC = 0·99). Test–retest reliability of fatigue variables was moderate for the knee extensor (ICC range 0·84–0·89) and insufficient-to-moderate for the knee flexor muscles (ICC range 0·78–0·81). The more reliable index of muscle fatigue was the linear slope of the decline in work output. These findings establish the reliability of isokinetic and isometric measurements using the Con-Trex machine.

Introduction

In both rehabilitation and sports medicine, accurate measurements of muscle function are required to assess the impact of therapeutic interventions or the effects of physical training. To this aim, isokinetic dynamometry has been introduced in the late 1960s and for more than two decades it has been the standard research tool to investigate muscle function of single muscle groups, more particularly the thigh muscles. Isokinetic muscle strength is typically measured as peak torque, average work and power (Perrin, 1993; Brown, 2000; Wrigley & Strauss, 2000). Isometric muscle strength can also be measured with these machines that includes the assessment of maximal voluntary contraction (MVC) torque and rate of torque development (RTD). Muscle fatigue (or endurance) – i.e. the decline in torque⁄work output across a series of contractions – is another feature that can be assessed using isokinetic techniques, usually at a relatively fast concentric velocity over 20–50 consecutive maximal-effort repetitions (Thorstensson & Karlsson, 1976; Kannus *et al.*, 1992; Kannus, 1994; Emery *et al.*, 1999; Pincivero et al., 2001).

Trustworthy isokinetic and isometric results require reliable measurement techniques. Reliability refers to the consistency of a test and can be expressed as intra and intersession. The measuring device itself, the procedure for conducting measurements, and the steadiness of the subject being measured are all helpful to determine the reliability of the method. Different studies have demonstrated acceptable intra and intersession reliability for various kinds of isokinetic machines, such as the Biodex (Brown *et al.*, 1993; Lund *et al.*, 2005), Cybex (Bandy & McLaughlin, 1993; Li *et al.*, 1996), Kin Com (Tredinnick & Duncan, 1988) and Merac (Capranica *et al.*, 1998). Other isokinetic dynamometers have been used in scientific studies (Lido, Orthotron, Technogym, etc.); however, the majority of these dynamometer manufacturers have left the market in the recent years.

The Con-Trex MJ isokinetic machine has been recently introduced to the rehabilitation-sports training community. Several scientific studies have used this device to assess static (isometric) and dynamic (eccentric and concentric) function of both the knee extensor and the flexor muscles (Cotte & Ferret, 2003; Bardis *et al.*, 2004; Harrison *et al.*, 2004; Mackey *et al.*, 2004; Koller *et al.*, 2006; Kilgallon *et al.*, 2007). However, there is a lack of information on the reliability of the Con-Trex machine for the assessment of isometric and eccentric variables – including isokinetic angle of peak torque – as well as for muscle fatigue assessment.

The aim of this study was to investigate test–retest reliability (both within and between sessions) of the knee extensor and the flexor muscle function (strength and fatigue) assessment using a new isokinetic device, in a group of healthy individuals from both sexes.

Methods

Subjects and experimental procedures

According to the recommendations of Walter *et al.* (1998) on sample size for reliability studies, 15 healthy men and 15 healthy women of age ranging from 23 to 42 (mean age ± SD: 30 ± 5 years, height: 175 ± 8 cm, mass: 70 ± 13 kg) were included in this study. All 30 were recreational athletes without known cardiovascular and orthopaedic problems. They were recruited from the Clinic staff. The study protocol was approved by the local ethical committee and written consent forms were signed prior to participation. The study was conducted according to the Declaration of Helsinki. Subjects were instructed to maintain their regular training regimens throughout the experimental period and not to take part in any vigorous physical activity for 2 days prior to their test date.

Testing

The subjects were tested during two identical sessions held 7 days apart, at the same time of day. All measurements were recorded by the same experimenter (NAM) to avoid intertester variability. The thigh muscles of the dominant limb (the limb used to kick a ball) were tested by using a commercially available dynamometer (Con-Trex MJ; CMV AG, Dübendorf, Switzerland), which allows instantaneous isokinetic and isometric torque recording. Subjects were comfortably seated on the dynamometer chair, with the hip joint at about 85° (0° = full extension). The distal shin pad of the dynamometer was attached 2–3 cm proximal to the lateral malleoulus by using a strap. To minimize extraneous body movements during thigh muscle contractions, straps were applied across the chest, pelvis and mid-thigh. The alignment between the dynamometer rotational axis and the knee joint rotation axis (lateral femoral epicondyle) was checked at the beginning of each trial. Gravity effect torque was recorded on each subject throughout the range of motion and this was used to correct torque measurements during all tests. The participants were given standardized (verbal) encouragement by the investigator (see below), and were asked to position their arms across the chest with each hand clasping the opposite shoulder during the testing procedure. On-line visual feedback of the instantaneous dynamometer torque was provided to the subjects on a computer screen.

The overview of the experimental protocol is depicted in Fig. 1. Subjects warmed-up by performing 20 submaximal (20–80% of the estimated maximum effort) concentric and eccentric contractions of the thigh muscles (reciprocal for knee extensors and knee flexors) at slow angular velocities (15 and −15° s^{-1}, respectively). Subjects were also asked to complete two to three submaximal practice repetitions prior to each test series. For the isokinetic trials, range of motion was 70°, from 80° to 10° of knee flexion (0° corresponding to knee

Series	Velocity	Muscle group	Trials	ROM/position
Warm-up	15 and –15°/s	KE and KF reciprocal	20	70°
Concentric	60°/s	KE and KF reciprocal	3	70°
Concentric	120°/s	KE and KF reciprocal	3	70°
Concentric	180°/s	KE and KF reciprocal	3	70°
Isometric	0°/s	KE	1	60° knee flexion
Isometric	0°/s	KF	1	60° knee flexion
Isometric	0°/s	KE	1	60° knee flexion
Isometric	0°/s	KF	1	60° knee flexion
Eccentric	-60°/s	KE	3	70°
Eccentric	-60°/s	KF	3	70°
Fatigue test	180°/s	KE and KF reciprocal	20	70°

Figure 1 Experimental protocol. Rest periods of 1 min were interspersed between series. KE, knee extensors; KF, knee flexors; ROM, range of motion.

fully extended). Concentric measurements involved three continuous, reciprocal (maximal) knee extensions and flexions, which were performed at three preset constant angular velocities, in the following order: 60, 120, 180° s^{-1} (slow to fast) (Wilhite *et al.*, 1992). Eccentric measurements consisted of three maximal contractions at a single velocity of −60° s^{-1}. Knee flexor and extensor trials were performed as discrete movements in a single direction (i.e. non-reciprocal). For both concentric and eccentric repetitions, subjects were exhorted to push⁄pull as hard and as fast as possible and to complete the full range of motion. For the isometric trials, the knee joint was fixed at an angle of 60° of flexion, which has been demonstrated to be the angle of maximal isometric force generation (Thorstensson *et al.*, 1976). Two isometric knee extensions and flexions were performed, and subjects were consistently asked to produce their maximal force rapidly (as fast and forceful as possible) and then to maintain the contraction for 4–5 s. After the maximal isokinetic and isometric contractions, subjects completed a fatigue test consisting of 20 continuous, reciprocal (maximal) knee extensions and flexions, which were performed at 180° s^{-1} (total duration ~20 s). Throughout the fatigue test, subjects were exhorted to push⁄pull as hard and as fast as possible and to complete the full range of motion. It was consistently verified that the average peak torque of the first three to five contractions was similar to the values recorded during the three-repetition series performed at 180° s^{-1} in the first part of the session, to ensure the maximal effort. Whatever the action mode and the velocity, subjects recovered passively for 60 s between series of measurements (isokinetic trials) or between repetitions (isometric trials). The Con-Trex software consistently indicated the duration of both contraction and rest phases.

Criterion measures

Torque, position and angular velocity data were recorded from the isokinetic dynamometer with a sampling rate of 100 Hz. For concentric and eccentric strength trials, the software calculated a large number of parameters, but we retained only those commonly used in isokinetic studies, namely the peak torque, the average work, the average power and the angle of peak torque (Brown *et al.*, 1992; Perrin, 1993; Brown, 2000; Wrigley & Strauss, 2000). These variables were calculated for the knee extensor and the flexor muscles. For each angular velocity, only the two trials giving the highest peak torque were considered. The velocity throughout each repetition was analysed and it was also verified that, at the faster angular velocity, peak torque was developed during the constant velocity period. Isometric torque data were exported and analysed with Windows-based software (Acqknowledge; Biopac Systems Inc., Santa Barbara, CA, USA). Isometric MVC torque, i.e. the highest torque value, and maximal RTD, i.e. the highest positive value from the first derivative of the torque signal (greatest slope of torque-time curve), were calculated for all knee extensor and flexor trials. For the fatigue test, only peak torque and average work associated with the 20 consecutive repetitions were retained. Data associated with the first contraction of each series were consistently removed from the analyses (see Fig. 2). For respective muscles, torque (Fig. 2a) and work (Fig. 2b) values associated with the first four repetitions (contraction 2–5) and last four repetitions (contraction 17–20) of the series were averaged and considered as prefatigue and postfatigue data, respectively. Peak torque and work losses were then calculated as the per cent difference between postfatigue and prefatigue data (Thorstensson & Karlsson, 1976). Moreover, the decline in torque and work via the negative slope was determined by linear regression analysis from the second to the last (20th) repetition (Pincivero *et al.*, 2000, 2001), for respective muscle groups (see Fig. 2).

Statistical analyses

For muscle strength parameters (peak torque, work, power, angle of peak torque, isometric MVC torque and RTD), within-session (trial 1 versus trial 2) and between-session (average of trials 1 and 2 of session 1 versus session 2) reliability were calculated. For muscle fatigue variables (prefatigue, postfatigue, per cent loss and slope of both peak torque and work data), only test–retest reliability was calculated.

Relative reliability concerns the degree to which individuals maintain their position in a sample with repeated measurements (Atkinson & Nevill, 1998). We assessed this type of reliability with the intraclass correlation coefficient (ICC) (2,1), a two-way random effects model with single-measure reliability in which variance over the repeated session is considered (Shrout & Fleiss, 1979). The ICC indicates the error in measurements as a proportion of the total variance in scores. As a general rule, we considered an ICC over 0·90 as high, between 0·80 and 0·90 as moderate and below 0·80 as insufficient (Vincent, 1999). Absolute reliability is the degree to which repeated measurements vary for individuals (Atkinson & Nevill, 1998); this type of reliability is usually expressed as a proportion of the measured values, i.e. coefficient of variation (CV). CV refers to intrasubject variation between two measurements. For each subject, CV was calculated as: (SD of two measurements⁄mean of two measurements) × 100. To interpret the CV values, we used the arbitrary suggestions made by Stokes (1985) with an analytical goal of 15% or below.

Following a repeated measures ANOVA on trials within the same session, paired sample t-tests (bilateral) were used to determine whether the average muscle strength and fatigue data obtained in the session 1 were significantly different from session 2. Statistical significance was set at $P<0{\cdot}05$. All statistical procedures were performed with SPSS 12.0.1 statistical software (SPSS Inc., Chicago, IL, USA).

Results

For all the criterion measures, as (i) CV were not significantly different (unpaired Student's t-test) and (ii) average ICC were

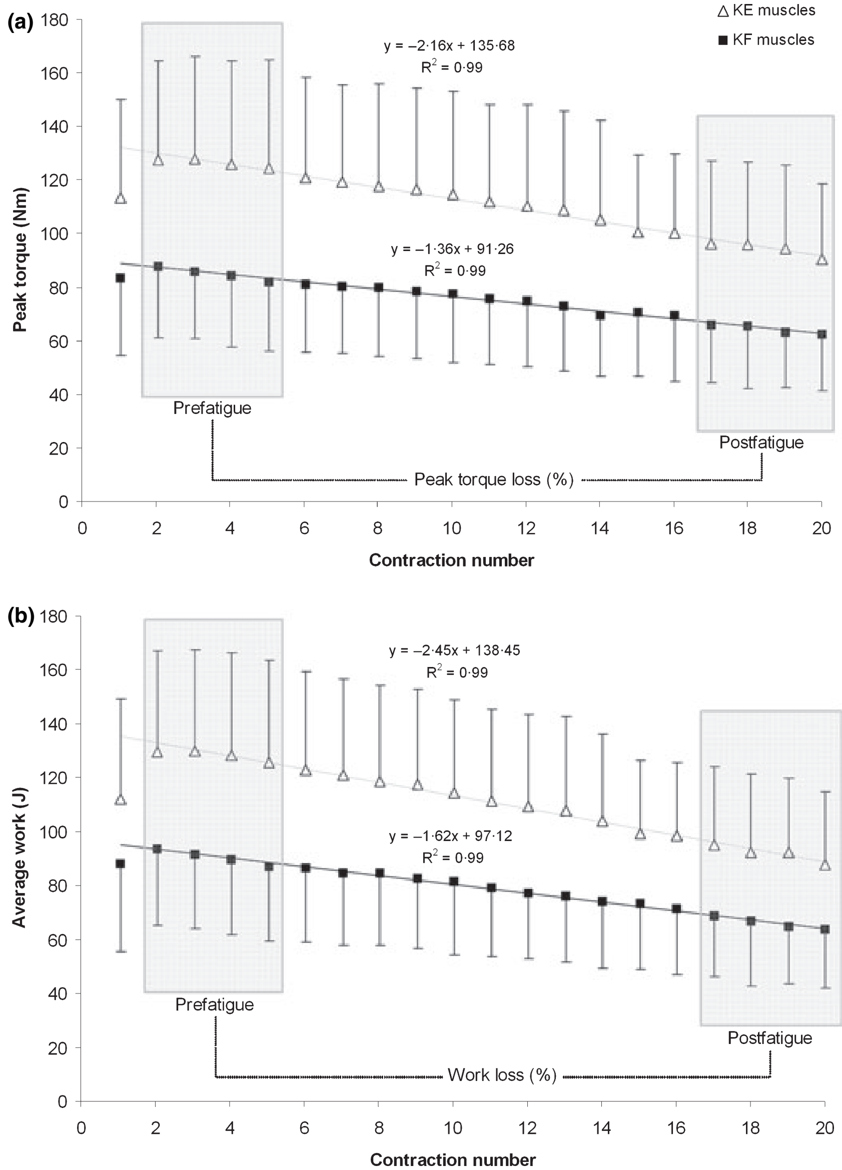

Figure 2 Decline in knee extensor and knee flexor peak torque (a) and average work (b) across the 20 repetitions (mean values of 30 subjects, session 1). The error bars represent SD. The average values of contraction 2–5 and 17–20 (shaded areas) were considered as prefatigue and postfatigue values, respectively. The difference between prefatigue and postfatigue data (peak torque and work loss) was calculated in per cent values. Moreover, torque and work losses were quantified as the slope of the linear fit for respective muscle groups. KE, knee extensors; KF, knee flexors.

almost identical between men and women, all data were collapsed across gender.

Muscle strength

Mean isokinetic and isometric strength data for sessions 1 and 2, together with the associated CV and ICC for within and between-session reliability are presented in Table 1 (knee extensors) and Table 2 (knee flexors). For both muscle groups, isokinetic peak torque, work and power as well as isometric MVC torque and RTD demonstrated moderate-to-high reliability, with CV lower than 9·7% and ICC higher than 0·86. Concentric peak torque at the fastest velocity (180° s^{-1}) significantly increased from session 1 to session 2 for both the knee extensor and the flexor muscles ($P<0·05$). In the same way, eccentric peak torque ($P<0·05$), work ($P<0·01$) and power ($P<0·01$) of the knee extensor muscles as well as angle of peak torque at 60° s^{-1} ($P<0·05$) significantly increased from session 1 to session 2. For the knee extensor muscles, angle of peak torque data showed a high reliability for the concentric but not for the eccentric mode (low ICC). Both within and between-session reliability for the knee flexors angle of peak torque was insufficient (low ICC), except for 180° s^{-1}.

To gain insight into (between-session) reliability results, CV and ICC data were grouped as a function of muscle group (knee extensors versus flexors), isokinetic variable (peak torque versus work versus power versus angle of peak torque) and angular velocity (−60 versus 0 versus 60 versus 120 versus 180° s^{-1}). We observed the highest ICC and the lowest CV (i.e. better reliability), respectively, for knee extensors (Fig. 3a), peak torque (Fig. 3b) and 180° s^{-1} data (Fig. 3c), while knee flexors, angle of peak torque and eccentric data showed the lowest reliability.

Table 1 Reliability of isokinetic and isometric muscle strength data for the knee extensors.

	Mean ± SD		Within-session reliability		Between-session reliability	
	Session 1	Session 2	CV	ICC	CV	ICC
Peak torque (N m)						
60° s^{-1}	177·7 ± 46·1	177·6 ± 45·9	2·8	0·996	3·2	0·978
120° s^{-1}	152·4 ± 40·2	154·9 ± 40·4	1·9	0·998	2·8	0·991
180° s^{-1}	132·5 ± 37·9	135·6 ± 38·9*	1·9	0·999	3·3	0·993
−60° s^{-1}	202·4 ± 68·0	211·4 ± 61·2*	3·4	0·995	7·0	0·965
Average work (J)						
60° s^{-1}	169·9 ± 42·1	168·1 ± 41·2	2·7	0·996	4·1	0·966
120° s^{-1}	152·9 ± 40·8	152·9 ± 38·4	2·1	0·998	3·7	0·979
180° s^{-1}	136·7 ± 39·7	137·5 ± 38·4	2·4	0·999	4·0	0·986
−60° s^{-1}	172·0 ± 56·4	182·6 ± 53·3**	3·9	0·994	7·2	0·971
Average power (W)						
60° s^{-1}	119·0 ± 28·1	120·4 ± 30·1	2·8	0·996	4·7	0·956
120° s^{-1}	187·1 ± 48·5	188·9 ± 46·2	2·6	0·996	3·4	0·983
180° s^{-1}	218·8 ± 64·1	223·0 ± 64·3	2·9	0·998	4·6	0·981
−60° s^{-1}	125·3 ± 41·0	133·5 ± 39·9**	4·3	0·993	7·3	0·971
Angle of peak torque (°)						
60° s^{-1}	53·4 ± 6·9	55·2 ± 7·4*	4·0	0·927	4·3	0·914
120° s^{-1}	47·6 ± 7·1	48·1 ± 6·7	3·5	0·968	4·3	0·920
180° s^{-1}	47·1 ± 6·6	47·2 ± 6·8	4·1	0·943	4·0	0·911
−60° s^{-1}	60·4 ± 7·1	62·3 ± 7·9	6·9	0·766	7·1	0·483
Isometric MVC torque (N m)	214·1 ± 61·9	221·4 ± 57·6	4·4	0·983	5·5	0·972
Isometric RTD (N m s)	521·2 ± 161·3	513·2 ± 143·9	8·3	0·923	9·1	0·874

CV, coefficient of variation; ICC, intraclass correlation coefficients; MVC, maximal voluntary contraction; RTD, rate of torque development. Significantly higher than session 1 at *$P<0·05$ and **$P<0·01$, respectively.

Table 2 Reliability of isokinetic and isometric muscle strength data for the knee flexors.

	Mean ± SD		Within-session reliability		Between-session reliability	
	Session 1	Session 2	CV	ICC	CV	ICC
Peak torque (N m)						
60° s^{-1}	109·2 ± 30·9	109·6 ± 30·5	3·6	0·995	3·1	0·988
120° s^{-1}	96·7 ± 28·2	98·1 ± 28·2	2·9	0·998	4·2	0·987
180° s^{-1}	88·3 ± 27·1	90·9 ± 25·9*	2·7	0·997	4·1	0·988
−60°s^{-1}	129·5 ± 38·0	129·7 ± 40·5	3·4	0·996	6·4	0·971
Average work (J)						
60° s^{-1}	111·0 ± 32·0	110·6 ± 29·6	3·4	0·995	3·8	0·977
120° s^{-1}	101·7 ± 29·7	101·5 ± 28·8	3·6	0·996	5·5	0·972
180° s^{-1}	93·4 ± 28·4	94·8 ± 27·2	3·2	0·996	4·1	0·985
−60° s^{-1}	123·8 ± 37·7	124·5 ± 37·8	4·0	0·993	5·7	0·976
Average power (W)						
60° s^{-1}	71·7 ± 21·9	76·4 ± 20·0	8·8	0·859	8·4	0·912
120° s^{-1}	119·7 ± 36·4	122·5 ± 37·5	6·2	0·978	6·9	0·962
180° s^{-1}	144·7 ± 44·2	148·7 ± 42·7	4·9	0·992	6·1	0·960
−60° s^{-1}	90·6 ± 27·6	91·8 ± 27·9	4·0	0·993	5·9	0·975
Angle of peak torque (°)						
60° s^{-1}	29·7 ± 6·8	27·8 ± 5·6	10·2	0·769	11·1	0·520
120° s^{-1}	35·7 ± 7·7	35·2 ± 10·2	10·2	0·706	10·2	0·703
180° s^{-1}	43·8 ± 16·5	40·0 ± 15·1	8·4	0·907	11·6	0·836
−60° s^{-1}	24·1 ± 9·5	25·3 ± 8·1	13·5	0·931	18·1	0·731
Isometric MVC torque (N m)	106·5 ± 32·5	107·7 ± 33·2	3·4	0·991	4·7	0·975
Isometric RTD (N m s)	247·2 ± 77·8	252·3 ± 82·6	9·7	0·906	9·3	0·902

CV, coefficient of variation; ICC, intraclass correlation coefficients; MVC, maximal voluntary contraction; RTD, rate of torque development. *Significantly higher than session 1 at $P<0·05$.

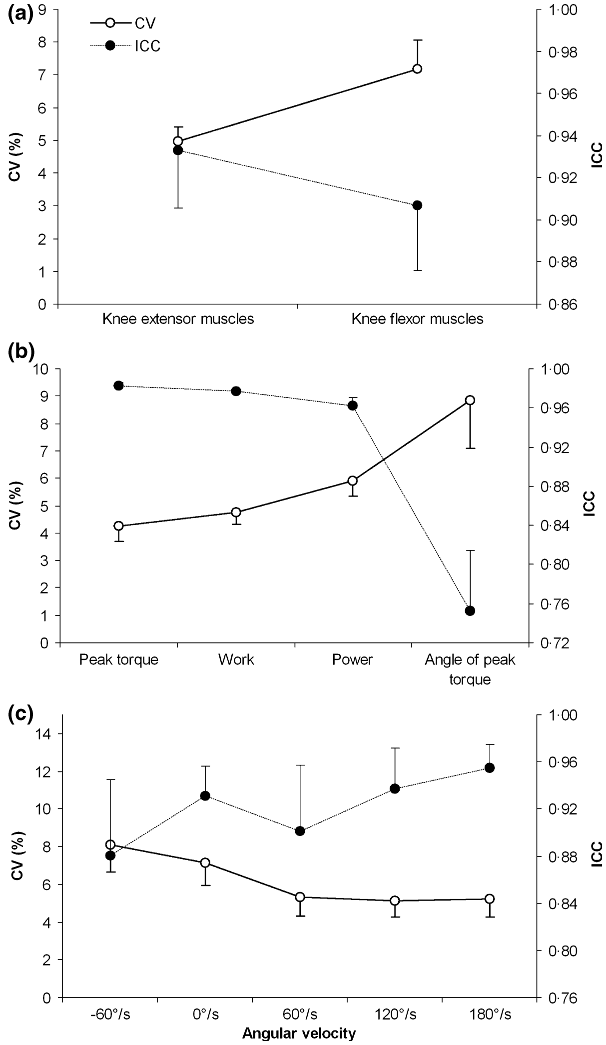

Figure 3 Between-session CV and ICC for strength variables collapsed across muscle group (a), isokinetic variable (b) and angular velocity (c). Mean values and SEM. CV: coefficient of variation; ICC: intraclass correlation coefficient.

Muscle fatigue

Isokinetic muscle fatigue data for respective sessions, together with the associated ICC are presented in Table 3 (knee extensors) and Table 4 (knee flexors). Absolute isokinetic peak torque and work ($P<0·001$) of the knee extensor and flexor muscles significantly decreased in the fatigued state. Isokinetic knee extension torque (but not work) was significantly higher at retest compared to session 1, both pre- and postfatigue ($P<0·05$).

For both muscle groups, pre and postfatigue isokinetic variables (absolute data), demonstrated high between-session reliability, with ICC higher than 0·98. Test–retest reliability of isokinetic fatigue indices (per cent loss and linear regression slope) was moderate for the knee extensor muscles (ICC range 0·84–0·89) and insufficient-to-moderate for the knee flexor muscles (ICC range 0·78–0·81).

Table 3 Reliability of muscle fatigue data for the knee extensors.

	Mean ± SD		Test–retest reliability ICC
	Session 1	Session 2	
Peak torque			
Prefatigue (N m)	127·6 ± 38·5	131·2 ± 37·5**	0·987
Postfatigue (N m)	95·0 ± 30·1*	97·8 ± 33·0*,**	0·988
Per cent loss	−25·6 ± 6·4	−26·0 ± 5·7	0·840
Slope	−2·16 ± 0·85	−2·20 ± 0·67	0·847
Work			
Prefatigue (J)	129·1 ± 37·4	131·6 ± 35·7	0·979
Postfatigue (J)	92·5 ± 27·9*	94·0 ± 28·7*	0·987
Per cent loss	−28·3 ± 7·0	−28·9 ± 5·5	0·869
Slope	−2·45 ± 0·96	−2·51 ± 0·71	0·889

ICC, intraclass correlation coefficients. *Significantly lower than prefatigue at P<0·001. **Significantly higher than session 1 at P<0·05.

Table 4 Reliability of muscle fatigue data for the knee flexors.

	Mean ± SD		Test–retest reliability ICC
	Session 1	Session 2	
Peak torque			
prefatigue (N m)	86·1 ± 25·9	88·4 ± 25·3	0·983
Postfatigue (N m)	65·3 ± 21·7*	67·8 ± 23·2*	0·982
Per cent loss	−24·5 ± 6·5	−23·9 ± 9·3	0·809
Slope	−1·36 ± 0·51	−1·34 ± 0·62	0·782
Work			
Prefatigue (J)	91·0 ± 27·8	92·1 ± 26·9	0·980
Postfatigue (J)	66·5 ± 22·3*	67·8 ± 23·1*	0·981
Per cent loss	−27·2 ± 6·8	−26·8 ± 9·0	0·788
Slope	−1·62 ± 0·54	−1·59 ± 0·68	0·814

ICC, intraclass correlation coefficients. *Significantly lower than prefatigue at P<0·001.

In order to speculate on the reliability of fatigue variables, we grouped the ICC data reported in Tables 3 and 4 as a function of muscle group (knee extensors versus flexors), isokinetic variable (peak torque versus work) and method of fatigue calculation (per cent loss versus slope). As a general rule, the highest ICC (i.e. better reliability) was observed for knee extensors (Fig. 4a), work (Fig. 4b) and slope (Fig. 4c) data, respectively. On the other hand, knee flexor muscles, peak torque and per cent loss had the lowest ICC.

Discussion

In the present study, the reliability of concentric, eccentric and isometric muscle strength assessment using the Con-Trex dynamometer was high for both the knee extensor and the flexor muscles. On the other hand, reliability varied from insufficient to high for angle of peak torque. The findings of this study also showed that test–retest reliability of fatigue indices was moderate for the knee extensor and insufficient-to-moderate for the knee flexor muscles.

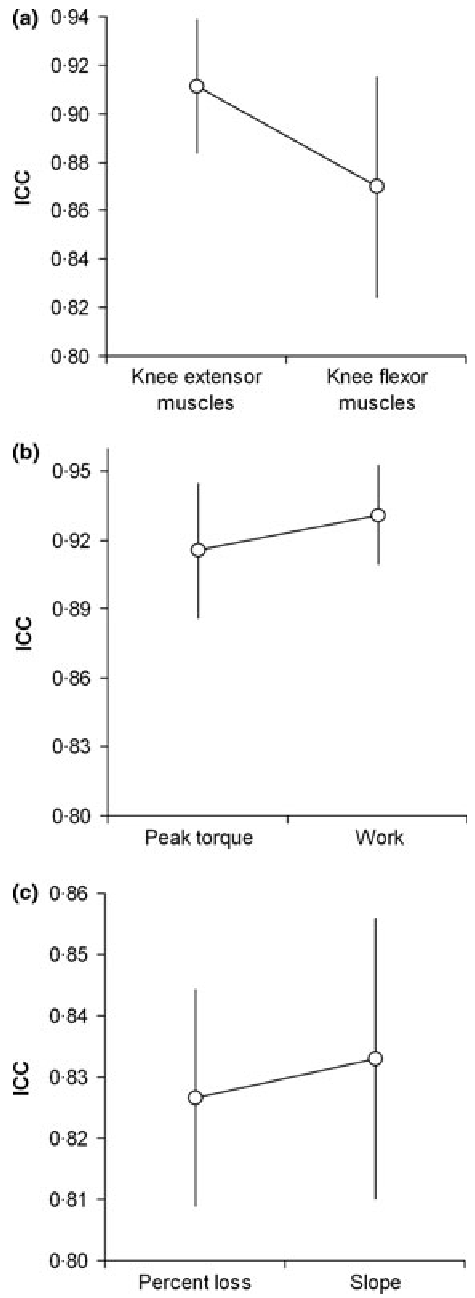

Figure 4 Average ICC for fatigue variables collapsed across muscle group (a), isokinetic variable (b) and method of fatigue calculation (c). Mean values and SEM. ICC: intraclass correlation coefficient.

The reliability of isokinetic measurement procedures and devices must be substantiated before dynamometers can be used for legitimate research or patient evaluation. To our knowledge, there are nowadays three main manufacturers vending isokinetic devices throughout the world: CSMI solutions (Stoughton, MA, USA) for Humac Norm (Cybex), Biodex Medical System (Shirley, NY, USA) for Biodex system 3 and CMV AG for Con-Trex MJ. In the last 20 years, test–retest reliability for the assessment of thigh muscle strength using Cybex and Biodex machines has been the focus of a series of manuscripts (Feiring *et al.*, 1990; Bandy & McLaughlin, 1993; Bemben & Johnson, 1993; Brown *et al.*, 1993; Li *et al.*, 1996; Drouin *et al.*, 2004; Lund *et al.*, 2005). Conversely, the reliability of measurements performed on the Con-Trex system, which is increasingly used to study thigh muscle function in both sports medicine (see e.g. Koller *et al.*, 2006) and research settings (see e.g. Mackey *et al.*, 2004), has not been clearly documented. Even if the comparison between studies is only anecdotal, the highest ICC for peak torque were obtained in this present investigation, both during concentric (ICC > 0·98 here versus 0·87–0·97 in the aforementioned studies) and eccentric (ICC > 0·96 versus 0·83–0·84) actions. Another unique aspect of this study is the assessment of isometric strength and isokinetic fatigue in addition to isokinetic (eccentric and concentric) strength variables, for both the knee extensor and the flexor muscles.

All isokinetic and isometric strength outcomes based on torque recordings demonstrated moderate-to-high reliability. In contrast, the angle of occurrence of isokinetic peak torque, which is an important diagnostic parameter to consider (Bemben & Johnson, 1993), was quite unreliable for eccentric actions of the knee extensor muscles and for both concentric and eccentric actions of the knee flexor muscles. It is therefore recommended that this parameter – as provided by Con-Trex software – should be interpreted with caution. In order to provide methodological recommendations in the choice of variables that should be used in future studies to describe thigh muscle strength, reliability data (ICC and CV) were collapsed across muscle group, isokinetic variable and angular velocity (see Fig. 3). In line with Li *et al.* (1996) reliability was higher for the knee extensor compared to knee flexor muscles, and for peak torque compared with work and power. It is, therefore, recommended that the more reliable strength test performed with the Con-Trex dynamometer would consist of maximal-effort concentric isokinetic knee extensions, for which peak torque will be retained.

By using the same procedure, we demonstrated that test–retest reliability of muscle fatigue indices was better for (i) work rather than peak torque, (ii) linear slope rather than per cent decrease and (iii) knee extensor rather than knee flexor muscles. Isokinetic work is quantified as the area under the torque versus angle curve, and therefore characterizes muscle performance over the entire range of motion (70° in this study), whereas peak torque is recorded at one specific joint position. In the same way, the decrease in muscle performance via the negative slope was determined by considering all the repetitions (except the first), while per cent loss was calculated using the first and last four contractions of the series. Thus, it is evident that reliable fatigue measurements require the quantification of the greatest amount of data, both within a single contraction (work versus peak torque) and throughout a series of fatiguing contractions (slope versus loss). We conclude that the more reliable index of muscle fatigue through 20 maximal isokinetic repetitions performed with the Con-Trex device is the linear slope of the decline in work output. These results confirm and extend those of Pincivero *et al.* (2001); however, this method remains to be consistently used in the literature and included by manufacturers in isokinetic evaluations and reports.

The present findings establish the reliability of isokinetic and isometric muscle strength and fatigue measurements using the Con-Trex MJ machine. Future studies should determine (i) whether the results obtained on this isokinetic dynamometer are interchangeable with respect to machines of different brands and (ii) the reliability of the present muscle strength and fatigue assessments in patient populations.

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