Reliability of isokinetic strength imbalance ratios measured using the Cybex NORM dynamometer

Franco M. Impellizzeri[1], Mario Bizzini[1], Ermanno Rampinini[2], Ferdinando Cereda[3] and Nicola A. Maffiuletti[1]

[1]Neuromuscular Research Laboratory, Schulthess Clinic, Zurich, Switzerland, [2]Human Performance Laboratory, Mapei Sport Research Center, Castellanza, Varese, Italy, and [3]Corso di laurea in Scienze Motorie, Università Cattolica, Milano, Italy

Correspondence
Franco M. Impellizzeri, Neuromuscular Research Laboratory, Schulthess Clinic, Lengghalde 2, 8008 Zurich, Switzerland
E-mail: franco.impellizzeri@kws.ch

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Summary

The main aim of this study was to examine the absolute and relative reliability of some commonly used strength imbalance indices such as concentric hamstring-to-concentric quadriceps ratio, eccentric hamstring-to-concentric quadriceps ratio and bilateral concentric and eccentric strength ratios. An additional aim was to examine the reliability of the peak torque and work of the knee extensor and flexor muscles measured using the Cybex NORM dynamometer. Eighteen physically active healthy subjects (mean ± standard deviation, age 23 ± 3 years, height 176 ± 5 cm, body mass 74 ± 8 kg) were tested three times with 96 h between sessions. Peak torque, average work, unilateral and bilateral ratios were determined at 60, 120, 180 and −60° s^{-1}. Low (0·34) to moderate (0·87) relative reliability (intraclass correlation coefficient, ICC) was found for strength imbalance ratios with eccentric hamstring-to-concentric quadriceps ratio showing the greater ICC (>0·80). High ICC values (0·90–0·98) were found for peak torque and average work. Absolute reliability (standard error of measurement) ranged from 3·2% to 8·7% for strength imbalance ratios and from 4·3% to 7·7% for peak torque and average work measurements. This study established the reliability of the most common strength imbalance ratios and of absolute isokinetic muscle strength assessed using the Cybex NORM.

Introduction

In rehabilitation and sports medicine, various lower limb strength imbalance ratios are commonly used to monitor rehabilitation programmes and to identify possible risk factors for developing knee or hamstring injury and re-injury (Kannus, 1994; Croisier *et al.*, 2002, 2003; Dauty *et al.*, 2003; Croisier, 2004; Devan *et al.*, 2004). The concentric hamstring-to-quadriceps ratio (H_{conc}:Q_{conc}) describes the strength characteristics of the muscles at the knee joint. This index is typically calculated as the ratio between the peak torque of the hamstring and quadriceps measured during concentric contractions using isokinetic dynamometers (Heiser *et al.*, 1984). Dvir *et al.* (1989) and later Aagaard *et al.* (1995, 1998) have proposed the use of the dynamic control ratio as it should reflect the ability of the hamstring to counteract the anterior tibial shear during maximal quadriceps muscular contractions. This imbalance index is calculated as the ratio between eccentric hamstring strength relative to concentric quadriceps strength (H_{ecc}:Q_{conc}).

Other than H:Q ratios, bilateral strength asymmetry ratios of both quadriceps and hamstrings are widely used in sports medicine to quantify the functional deficit consequent to knee injury and/or surgery and to decide whether the athlete is ready to return to competition (Heiser *et al.*, 1984; Clark, 2001; Wilk *et al.*, 2003). Furthermore, as various prospective and retrospective studies have shown a relationship between lower limb strength imbalance and hamstring or knee injuries (Ekstrand & Gillquist, 1983; Knapik *et al.*, 1991; Yamamoto, 1993; Dvorak & Junge, 2000; Croisier *et al.*, 2002; Dauty *et al.*, 2003; Devan *et al.*, 2004), some authors proposed the use of preseason screening of unilateral and bilateral strength imbalance in healthy subjects to identify athletes at increased risk of incurring lower limb injuries during training and competition (Heiser *et al.*, 1984; Croisier, 2004).

However, to be used for monitoring rehabilitation and training interventions or as screening test of muscular function in healthy subjects, reliable measures of strength imbalance are essential. The more reliable the measure the higher would also be the probability of adequate sensitivity to track small but clinically important changes. Furthermore, the knowledge of the reliability of these imbalance indices may explain for the inconsistency observed in previous studies investigating the role of lower limb strength imbalance as risk factor for musculoskeletal injuries (Grace *et al.*, 1984; Bennell *et al.*, 1998). Several investigations have demonstrated acceptable reliability for the peak torque and average work measured using various kinds of isokinetic dynamometers such as Con-trex, Biodex, Lido, Kin Com, etc. (Bandy & McLaughlin, 1993; Brown et al., 1993; Li et al., 1996; Lund et al., 2005; Maffiuletti et al., 2007). However, surprisingly, very few studies examined the reliability of lower limb strength imbalance indices in spite of their widespread use (e.g. Gleeson & Mercer, 1992; Hsu et al., 2002). Besides, these investigators have shown low to moderate reliability for H_{conc}:Q_{conc} ratio (Gleeson & Mercer, 1992) and bilateral strength imbalance (Hsu et al., 2002). To the authors' knowledge, the reliability of the dynamic control ratio has never been reported.

The main aim of this study was to examine the absolute and relative reliability of some commonly used strength imbalance indices such as H_{conc}:Q_{conc}, H_{ecc}:Q_{conc} and bilateral concentric and eccentric ratios. An additional aim was to examine the reliability of the peak torque and work of the knee extensor and flexor muscles measured using the Cybex NORM dynamometer, which has never been studied.

Methods

Subjects and experimental procedures

Eighteen physically active healthy subjects ranging in age from 21 to 28 years (mean age ± SD: 23 ± 3 years, height: 176 ± 5 cm, body mass: 74 ± 8 kg) and with no previous experience with isokinetic tests volunteered to participate in the study. All 18 were recreational athletes without known cardiovascular and orthopaedic problems. Fourteen of them were right dominant (defined as the limb used to kick a ball). Subjects were instructed to maintain their regular training regimens throughout the experimental period and not to take part in any vigorous physical activity for the duration of the study period. Before participating, all subjects gave their written informed consent. The study was approved by an Independent Institutional Review Board according to the guidelines and recommendations for the European ethics committees by the European Forum for good clinical practice.

Testing procedures

The subjects were tested three times with 96 h between the sessions, at the same time of the day. All measurements were conducted by the same experimenter (Ferdinando Cereda) to avoid intertester variability. Maximal strength of the knee extensor and flexor muscles was measured using an isokinetic dynamometer (Cybex NORM®, Humac, CA, USA) which allowed recording of instantaneous isokinetic torque. Subjects were positioned on an adjustable chair and secured to the equipment with straps across the trunk, hip and 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. Range of motion was set at 10–90° (0° corresponding to knee fully extended). Before each test the gravity compensation procedure was performed according to the manufacturer's instructions. The subjects were instructed to push as hard as possible against a shin pad secured to the distal tibia. The shin pad was attached about 5 cm proximal to the lateral malleoulus by using a strap. The participants were given standardized (verbal) encouragement by the investigator and were asked to position their arms across the chest with each hand clasping the opposite shoulder during the maximal effort trials. On-line visual feedback of the instantaneous dynamometer torque was provided to the subjects on a computer screen.

Subjects warmed-up by performing 20 submaximal concentric (60° s^{-1}) and eccentric (−60° s^{-1}) contractions of the thigh muscles (reciprocal for quadriceps and hamstrings). Subjects were also asked to complete five to six submaximal practice repetitions prior to each test series. Concentric measurements involved three continuous, reciprocal (maximal) knee extensions–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}. Eccentric 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/resist as hard and as fast as possible and to complete the full range of motion. Whatever the action mode and the velocity, subjects recovered passively for 60 s between series of measurements. The Cybex NORM software consistently indicated visually and verbally the duration of the rest phases. The highest peak torque and average work of the three repetitions was selected for analyses. To avoid artefacts, only peak torques in the load range were considered (Brown et al., 1995).

Strength imbalance ratios

Unilateral ratios

The strength difference between the hamstrings and quadriceps of the same limb (unilateral) was calculated as the ratio between the peak torque produced concentrically during the isokinetic tests (H_{conc}:Q_{conc}). The dynamic control ratio was calculated as the ratio between the peak torque produced eccentrically by the hamstrings, and concentrically by the quadriceps.

Bilateral ratios

In the literature (Knapik et al., 1991; Yamamoto, 1993; Keays et al., 2003), bilateral lower limb strength asymmetry has been calculated in different ways: (i) injured/non-injured; (ii) right/left; (iii) stronger/weaker. The first method can be applied only to injured athletes and therefore was not utilized in the current study which includes healthy subjects. The second method has the disadvantage of providing different values of relative asymmetry when using the right limb as the numerator irrespective of its functional status (weaker or stronger). For example, an absolute strength asymmetry of 40 Nm in a subject with a stronger right leg (right leg = 200 Nm; left leg = 160 Nm) would correspond to 1·25 (i.e. +25%). If the same subject has the left leg stronger, the ratio would be 0·80 (i.e. –20%). The third method does not suffer from the problem mentioned here, but always gives positive values. This is a problem when calculating reliability as there is the possibility that the strong limb becomes the weaker in a subsequent assessment. To overcome these shortcomings, in the present study we calculated the bilateral strength ratio according to the second method (right/left) but log transforming the values for the analysis. Indeed, after log transformation of 1·25 and 0·80 from the example mentioned here, the ratios become 0·22 and –0·22.

Statistical analyses

Unless otherwise noted, all data were presented as mean ± one standard deviation (SD). Detection of systematic biases was performed using a repeated measures ANOVA with Huyhn-Feldt correction for sphericity, and Bonferroni *post-hoc* test (Atkinson & Nevill, 1998). Heteroscedasticity was examined by plotting the residual versus predicted values and calculating the Pearson's correlation coefficient with significant correlations indicating heteroscedasticity, i.e. error depending on the magnitude of the mean.

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 the 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. We considered an ICC over 0·90 as high, between 0·80 and 0·90 as moderate and below 0·80 as low (Vincent, 1995). Absolute reliability is the degree to which repeated measurements vary for individuals (i.e. trial-to-trial noise) (Atkinson & Nevill, 1998). We expressed this type of reliability with the standard error of measurement (SEM) calculated as the square root of the mean square error (MSE) term derived from the two-way ANOVA results (Stratford & Goldsmith, 1997; Hopkins, 2000). The 95% limits of agreement for the determination of the minimum detectable change (MDC) has been calculated as $\pm 1{\cdot}96 \cdot \sqrt{2 \cdot \mathrm{MSE}}$ (Atkinson & Nevill, 1998; Weir, 2005). SEM has been presented as per cent of the mean value. For bilateral ratios the reported %SEM values were obtained by antilogging the results derived from the analysis of normalized data.

The probability of type I error (alpha) was set *a priori* at 0·05 in all statistical analyses. All statistical procedures were performed with SPSS 13·0 statistical software (SPSS Inc., Chicago, IL, USA).

Results

Reliability of strength imbalance ratios

Table 1 presents the mean ± SD, ICC, SEM and MDC of unilateral and bilateral strength imbalance ratios obtained for the three trials. ICC values for H_{conc}:Q_{conc} resulted low at all speeds. Relative reliability was moderate only for the H_{ecc}:Q_{conc}.

Table 1 Reliability of the lower limb strength imbalance indices.

Parameters	Mean ± SD			Main effect *P*-value	ICC (2,1)	95% CI Lower; Upper	SEM (%) ± MDC (%)
	Day 1	Day 2	Day 3				
Unilateral hamstring-to-quadriceps ratio – right							
Concentric at 60° s^{-1}	0·56 ± 0·07 *	0·59 ± 0·07	0·59 ± 0·07	0·001	0·79	0·61; 0·91	5·4 ± 15·0
Concentric at 120° s^{-1}	0·58 ± 0·05**	0·61 ± 0·05	0·60 ± 0·05	0·052	0·70	0·46; 0·86	5·3 ± 14·7
Concentric at 180° s^{-1}	0·60 ± 0·05	0·62 ± 0·05	0·61 ± 0·04	0·311	0·34	0·05; 0·64	5·2 ± 14·4
Eccentric-to-concentric at −60° s^{-1}	0·69 ± 0·10*	0·71 ± 0·12	0·73 ± 0·12	0·018	0·87	0·75; 0·95	6·3 ± 17·5
Unilateral hamstring-to-quadriceps ratio – left							
Concentric at 60° s^{-1}	0·56 ± 0·05**	0·60 ± 0·05	0·58 ± 0·06	0·015	0·65	0·40; 0·83	5·5 ± 15·1
Concentric at 120° s^{-1}	0·62 ± 0·05	0·62 ± 0·04	0·63 ± 0·06	0·711	0·55	0·28; 0·78	5·1 ± 14·1
Concentric at 180° s^{-1}	0·63 ± 0·06	0·65 ± 0·05	0·62 ± 0·06	0·199	0·44	0·15; 0·71	7·1 ± 19·6
Eccentric-to-concentric at −60° s^{-1}	0·67 ± 0·09**	0·71 ± 0·10	0·71 ± 0·11	0·023	0·80	0·63; 0·91	6·4 ± 17·6
Bilateral quadriceps ratio[a]							
Concentric at 60° s^{-1}	0·96 ± 0·09	0·95 ± 0·09	0·96 ± 0·09	0·691	0·78	0·59; 0·90	3·2 ± 8·9
Concentric at 120° s^{-1}	0·95 ± 0·07	0·97 ± 0·09	0·96 ± 0·07	0·460	0·63	0·37; 0·83	5·6 ± 15·6
Concentric at 180° s^{-1}	0·96 ± 0·07	0·97 ± 0·09	0·97 ± 0·09	0·888	0·43	0·14; 0·70	6·5 ± 18·1
Eccentric at −60° s^{-1}	0·91 ± 0·10	0·93 ± 0·13	0·92 ± 0·10	0·668	0·65	0·40; 0·84	7·3 ± 20·3
Bilateral hamstring ratio[a]							
Concentric at 60° s^{-1}	0·96 ± 0·08	0·97 ± 0·12	0·94 ± 0·14	0·240	0·59	0·32; 0·80	8·7 ± 24·2
Concentric at 120° s^{-1}	1·00 ± 0·07	1·00 ± 0·09	0·99 ± 0·09	0·900	0·29	0·01; 0·60	7·3 ± 20·3
Concentric at 180° s^{-1}	1·00 ± 0·08	1·02 ± 0·09	1·01 ± 0·08	0·649	0·54	0·27; 0·78	5·6 ± 15·6
Eccentric at −60° s^{-1}	0·93 ± 0·10	0·96 ± 0·09	0·95 ± 0·14	0·294	0·69	0·45; 0·86	7·3 ± 20·3

ICC, intraclass correlation coefficient; SEM, standard error of measurements; MDC, minimal detectable change; CI, confidence interval.
[a]For clarity, data are presented as ratio (right/left) but statistical analyses were performed after log transformation of data.
*$P < 0{\cdot}05$, significantly lower than day 2 and 3; **$P < 0{\cdot}05$, significantly lower than day 2.

Similarly, all the ICC values for the bilateral quadriceps and hamstring ratio showed low relative reliability. A significant effect of time was found for H_{conc}:Q_{conc} and H_{ecc}:Q_{conc} ratios, that were lower for the first trial compared with the second and third trials. This effect was not found for the bilateral ratios. No heteroscedasticity was found.

Absolute reliability ranged from 5·1% to 7·1% for H:Q ratios resulting in MDC between 14·1% and 19·6%. Lower absolute reliability (i.e. greater SEM and MDC) was found for bilateral imbalance indices, except at 60° s^{-1}.

Reliability of torque and work

Tables 2 and 3 present the mean ± SD, ICC, SEM and MDC of the peak torque and average work for the quadriceps and hamstrings. All the measures showed high relative reliability (>0·90) whatever the speed. A significant main effect of time was found for the peak torque of the knee flexors with the exclusion of the eccentric peak torque at −60° s^{-1}, with lower values during the first trial compared with the second and third trials. No systematic time effect was found for the knee extensors with the exclusion of the concentric peak torque at 180° s^{-1} (left). A significant main effect of time was only found for the average work of the knee flexors at 120° s^{-1} (left and right) and 60° s^{-1} (left), with lower values during the first trial compared with the second and third trials. No systematic time effect was found for the knee extensors. Overall, these results showed a moderate learning effect especially for the knee flexors.

Absolute reliability showed similar results compared with the strength imbalance indices, with SEM values ranging from 4·3% to 7·7% and MDC ranging from 11·1% to 21·2%. No heteroscedasticity was found.

Discussion

The results of this study showed a low to moderate relative reliability for the isokinetic strength imbalance ratios commonly used in rehabilitation and sports medicine. On the other hand, the reproducibility of absolute measures of isokinetic strength for knee extensor and flexors muscles using the Cybex NORM was high (relative reliability) and moderate (absolute reliability).

The evaluation of the reliability of isokinetic measurement procedures must be determined before these parameters can be used for legitimate research or patient evaluation. The knowledge of the reliability of strength imbalance indices is important to evaluate their potential sensitivity, calculate the sample size needed in intervention studies and to better interpret the results of previous studies in which these ratios have been used. However, despite the widespread use of imbalance indices such as H:Q and bilateral ratios, their reproducibility has been investigated only by few studies (e.g. Gleeson & Mercer, 1992; Hsu *et al.*, 2002). Hsu *et al.* (2002) examined the relative reliability of bilateral strength imbalance of hip flexors, knee extensors and ankle plantarflexors in nine stroke patients. They found ICC (3, 1) values of 0·42 at 30° s^{-1} and 0·81 at 90° s^{-1} for the bilateral quadriceps ratio using the peak torque. Their

Table 2 Reliability of the peak torque obtained during the isokinetic tests.

Peak torque (Nm)	Mean ± SD			Main effect *P*-value	ICC (2,1)	95% CI Lower; upper	SEM (%) ± MDC (%)
	Day 1	Day 2	Day 3				
Quadriceps – right							
Concentric at 60° s^{-1}	258 ± 77	256 ± 72	260 ± 79	0·576	0·98	0·95; 0·99	4·3 ± 12·0
Concentric at 120° s^{-1}	211 ± 65	213 ± 63	220 ± 63	0·044	0·97	0·95; 0·99	4·8 ± 13·2
Concentric at 180° s^{-1}	179 ± 54	184 ± 57	184 ± 59	0·056	0·98	0·96; 0·99	4·0 ± 11·1
Eccentric at −60° s^{-1}	332 ± 119	328 ± 108	326 ± 101	0·705	0·96	0·91; 0·98	6·8 ± 19·0
Hamstrings – right							
Concentric at 60° s^{-1}	137 ± 29*	146 ± 30	149 ± 36	<0·001	0·95	0·88; 0·98	5·2 ± 14·5
Concentric at 120° s^{-1}	118 ± 27*	129 ± 32	129 ± 33	<0·001	0·95	0·89; 0·98	5·7 ± 15·8
Concentric at 180° s^{-1}	106 ± 25*	111 ± 31	112 ± 31	0·006	0·96	0·92; 0·96	5·2 ± 14·3
Eccentric at −60° s^{-1}	174 ± 48	177 ± 48	175 ± 42	0·628	0·94	0·87; 0·98	6·5 ± 18·0
Quadriceps – left							
Concentric at 60° s^{-1}	240 ± 62	243 ± 67	245 ± 69	0·502	0·95	0·90; 0·98	4·7 ± 13·0
Concentric at 120° s^{-1}	200 ± 56	204 ± 61	209 ± 60	0·051	0·97	0·93; 0·99	5·3 ± 14·7
Concentric at 180° s^{-1}	169 ± 48**	174 ± 53	178 ± 52	0·006	0·98	0·95; 0·99	4·5 ± 12·5
Eccentric at −60° s^{-1}	290 ± 79	295 ± 84	295 ± 76	0·698	0·95	0·89; 0·98	6·2 ± 17·2
Hamstrings – left							
Concentric at 60° s^{-1}	133 ± 29*	142 ± 36	138 ± 37	0·024	0·93	0·85; 0·97	6·7 ± 18·6
Concentric at 120° s^{-1}	121 ± 30*	129 ± 34	127 ± 35	0·011	0·96	0·92; 0·98	5·2 ± 14·3
Concentric at 180° s^{-1}	108 ± 29*	114 ± 28	111 ± 31	0·005	0·97	0·93; 0·99	5·0 ± 13·9
Eccentric at −60° s^{-1}	158 ± 47*	169 ± 52	167 ± 54	0·003	0·97	0·94; 0·99	5·2 ± 14·5

ICC, intraclass correlation coefficient; SEM, standard error of measurements; MDC, minimal detectable change; CI, confidence interval.
*$P < 0·05$, significantly lower than day 2 and 3; **$P < 0·05$, significantly lower than day 3.

Table 3 Reliability of the average work obtained during the isokinetic tests.

Average work (J)	Mean ± SD Day 1	Day 2	Day 3	Main effect *P*-value	ICC (2,1)	95% CI Lower; upper	SEM (%) ± MDC (%)
Quadriceps – right							
Concentric at 60° s^{-1}	259 ± 71	258 ± 69	258 ± 76	0·923	0·98	0·95; 0·99	4·3 ± 11·9
Concentric at 120° s^{-1}	219 ± 62	219 ± 54	225 ± 61	0·264	0·96	0·91; 0·99	5·7 ± 15·8
Concentric at 180° s^{-1}	193 ± 51	193 ± 52	194 ± 56	0·942	0·96	0·92; 0·99	5·3 ± 14·7
Eccentric at −60° s^{-1}	331 ± 111	320 ± 106	323 ± 99	0·293	0·96	0·92; 0·98	6·5 ± 17·9
Hamstrings – right							
Concentric at 60° s^{-1}	148 ± 25	151 ± 26	153 ± 33	0·349	0·89	0·79; 0·96	6·0 ± 16·8
Concentric at 120° s^{-1}	132 ± 24*	140 ± 26	134 ± 29	0·007	0·93	0·85; 0·97	5·2 ± 14·3
Concentric at 180° s^{-1}	115 ± 27	119 ± 31	117 ± 31	0·144	0·96	0·90; 0·98	5·4 ± 15·0
Eccentric at −60° s^{-1}	186 ± 51	190 ± 47	181 ± 45	0·199	0·93	0·86; 0·97	6·6 ± 18·4
Quadriceps – left							
Concentric at 60° s^{-1}	245 ± 53	246 ± 58	248 ± 58	0·835	0·93	0·85; 0·97	6·2 ± 17·1
Concentric at 120° s^{-1}	207 ± 45	213 ± 52	214 ± 56	0·267	0·93	0·86; 0·97	6·3 ± 17·4
Concentric at 180° s^{-1}	181 ± 42	184 ± 45	185 ± 46	0·495	0·95	0·90; 0·98	5·4 ± 14·9
Eccentric at −60° s^{-1}	288 ± 71	296 ± 79	300 ± 81	0·253	0·91	0·82; 0·96	7·7 ± 21·2
Hamstrings – left							
Concentric at 60° s^{-1}	145 ± 29	152 ± 37	145 ± 34*	0·030	0·93	0·85; 0·97	6·2 ± 17·1
Concentric at 120° s^{-1}	133 ± 32*	139 ± 32	134 ± 36	0·020	0·95	0·89; 0·98	5·6 ± 15·5
Concentric at 180° s^{-1}	117 ± 32	123 ± 31	118 ± 31	0·074	0·94	0·87; 0·97	6·5 ± 18·1
Eccentric at −60° s^{-1}	170 ± 47	179 ± 53	174 ± 52	0·103	0·95	0·89; 0·98	6·6 ± 18·3

ICC, intraclass correlation coefficient; SEM, standard error of measurements; MDC, minimal detectable change; CI, confidence interval.
*$P < 0·05$, significantly lower than day 2.

results revealed better reliability at the slower speed compared with the faster speed. In another study, Gleeson & Mercer (1992) reported ICC values for the H_{conc}:Q_{conc} ratio ranging from 0·36 to 0·93 in 10 healthy men after one session of familiarization. Contrary to Hsu *et al.* (2002), the reliability was higher at low speeds (ICC from 0·78 to 0·93 at 60° s^{-1}) compared with high speeds (ICC from 0·36 to 0·70 at 180° s^{-1}). Taken together, these studies seem to show a moderate reliability of these imbalance ratios, as previously suggested by various authors (Gleeson & Mercer, 1996; Dauty *et al.*, 2003). Our results confirm the low relative reliability of bilateral ratios and H_{conc}:Q_{conc} ratios. Similar to Gleeson & Mercer (1992), we found slightly better ICC values at the slower speed compared with the faster speed.

Dvir *et al.* (1989) and Aagaard *et al.* (1995, 1998) suggested that H_{ecc}:Q_{conc} ratio may better describe the capacity for muscular knee joint stabilization compared with the traditional H_{conc}:Q_{conc} ratio. Indeed, during knee extension, the concentric action of the quadriceps muscle is combined with an eccentric contraction of the hamstrings. This co-activation of the knee flexor muscles contribute to counterbalance the shear and rotation of the tibia occurring during maximum knee extension (Dvir *et al.*, 1989; Aagaard *et al.*, 1995, 1998). Although the use of this relatively new ratio is growing (e.g. Dvir *et al.*, 1989; Aagaard *et al.*, 1997; Bennell *et al.*, 1998; Hole *et al.*, 2000; Cometti *et al.*, 2001; Dauty *et al.*, 2003; Hiemstra *et al.*, 2004; Rahnama *et al.*, 2005), to our knowledge, this is the first study examining the reliability of the dynamic control ratio. The ICC values for the H_{ecc}:Q_{conc} ratio measured at −60° s^{-1} were moderate but greater compared with the other traditional H:Q ratios. As the dynamic control ratio should reflect the synergistic action of quadriceps and hamstring during actual knee joint movements, the greater specificity of H_{ecc}:Q_{conc} ratio may explain, at least in part, its higher reliability compared with H_{conc}:Q_{conc} ratio.

Several studies have examined the reliability of isokinetic dynamometers such as the Biodex, Kin Com, Merac, Lido, Orthotron, Technogym, Con-Trex, etc. However, to the authors' knowledge, the reliability of the Cybex NORM, which is widely used in research and rehabilitation (Capodaglio *et al.*, 2005; Corin *et al.*, 2005), has not been reported. Indeed, in the literature we have found only studies examining the reliability of the Cybex 6000 (e.g. Li *et al.*, 1996; Dauty & Rochcongar, 2001) and Cybex II (Gross *et al.*, 1991) or comparing the Cybex NORM with the Con-Trex MJ (Cotte & Ferret, 2003; Bardis *et al.*, 2004). Therefore, an additional aim of the this study was to examine the reliability of the absolute peak torque and average work measured using the Cybex NORM. All these measures of isokinetic strength demonstrated high relative reliability. ICC values were higher or similar compared with those reported in previous studies examining earlier Cybex models (Gross *et al.*, 1991; Li *et al.*, 1996; Dauty & Rochcongar, 2001). In the present study, reliability was higher for knee extensors than knee flexors for peak torque compared with average work, in line with Li *et al.* (1996) and Maffiuletti *et al.* (2007). However, as the magnitude of the differences in ICC was very low, no parameter showed a clear superior reliability compared with the others.

Relative reliability concerns the degree to which individuals maintain their position in a sample with repeated measurements (Atkinson & Nevill, 1998). Therefore, ICC provides information about the ability of a measure to differentiate among the subjects (Stratford & Goldsmith, 1997). This may be very important when designing prospective and retrospective studies where the differences between the participants are the objective of the research. Therefore, the low reliability of the lower limb strength imbalance indices in addition to the multifactorial nature of injuries may explain the inconsistencies in the findings of previous studies investigating the role of strength imbalance as risk factor for musculoskeletal injuries (i.e. low statistical power). Relative reliability, however, is influenced by the between-subject variability and the heterogeneity of the sample (Atkinson & Nevill, 1998). Therefore, to evaluate the validity of a measure for intrasubject assessments, an index that takes into account the degree to which repeated measurements vary within the individual is necessary, i.e. absolute reliability (Atkinson & Nevill, 1998).

We determined the absolute reliability calculating the SEM as the square root of the mean square error term derived from the two-way ANOVA results (Stratford & Goldsmith, 1997; Hopkins, 2000). Contrary to ICC, the SEM is not affected by the between-subject variability (Hopkins, 2000; Weir, 2005) and allows the calculation of the MDC (95% confidence interval) which is the minimum difference that can be interpreted as 'real' with an acceptable probability level. While the relative reliability of strength imbalance indices was low and smaller than the absolute measures of isokinetic strength, the absolute reliability was similar with most of the SEM values ranging from 4% to 7% and MDC ranging from 10% to 20%, according to a previous study on the Cybex 6000 (Dauty & Rochcongar, 2001). This absolute reliability is also similar to that recently reported by Lund *et al.* (2005) for another widely used isokinetic device (Biodex). These authors found SEM values of about 7% for knee extensors and 9% for knee flexors, with the corresponding MDC ranging from 13% to 17%. Therefore, taken together, these findings suggest that individual changes higher or close to 20% are necessary to detect real changes. While Lund *et al.* (2005) suggested that these SEM and MDC values were indicators of high reliability, the interpretation of the reliability of a measure is a complex process. Indeed, the use of *a priori* criteria for the determination of an 'acceptable' level of reliability is inappropriate, as the acceptability of the reliability levels for a specific measure depends on the analytical goals (Atkinson & Nevill, 1998). For example, the MDC values reported in the present study may be acceptable to detect the large changes usually observed after rehabilitation programmes, but not acceptable to examine the effect of preventive training programmes in healthy subjects. Therefore, the acceptance of the measurement error (noise) should be always interpreted in relation to the magnitude of the signal (e.g. training-induced changes) which may vary according to the population and the effectiveness of the specific treatment.

A learning effect was found for the peak torque of the hamstrings (both left and right). This explains why the H_{conc}:Q_{conc} and not bilateral ratios increased between the first and the second trials. This learning effect may be related to biomechanical factors. Indeed, the seated position does not respect the length–tension relationship of the hamstrings during walking or running. For this reason, the prone or supine position has been suggested as a more specific position to test the knee flexor muscles (Perrin, 1993). Therefore, because of the unusual length of the knee flexor muscles in the seated position, it is possible that subjects not familiarized with isokinetic tests require one or more trial to adapt to the specific position. As no learning effects were found between trials 2 and 3, the use of one familiarization trial seems to be sufficient to ensure more consistent peak torque results.

In conclusion, this study established the reliability of the most common indices of strength imbalance ratios and of isokinetic muscle strength assessment using the Cybex NORM. Our findings suggest that unilateral and bilateral ratios have poor relative reliability and are more suitable for detecting large changes such as those associated to rehabilitation programmes. Therefore, imbalance ratios should be used and interpreted with caution, more particularly with healthy population (Gleeson & Mercer, 1992). Future studies should examine possible strategies designed to increase the reliability of these ratios, such as multiple tests in the same or different testing sessions (Gleeson & Mercer, 1996). Furthermore, studies examining the reliability in different populations are needed to ascertain the clinical application of isokinetic strength imbalance ratios (Steiner *et al.*, 1993).

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