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Reproducibility of isokinetic leg strength and endurance characteristics of adult men and women

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Summary. Day-to-day variability and single-measurement reliability of selected isokinetic knee extension-flexion strength and endurance indices were assessed in 10 adult men and 8 adult women. On three occasions separated by at least 5 days, the subjects completed 4 reciprocal maximal voluntary contractions (MVC) at different angular velocities (1.05 $rad \cdot s^{-1}$ and 3.14 $rad \cdot s^{-1}$). The men also completed a muscular endurance test consisting of 30 reciprocal, MVC at 3.14 $rad \cdot s^{-1}$. Coefficient of variation, intra-class correlation coefficient and standard error of single-measurement scores support the continued use of gravity corrected peak torque (PT) and average peak torque (APT) as indices of isokinetic leg strength. Similarly, gravity corrected APT and total work should be the recommended indices of isokinetic leg muscular endurance in men. The results suggest that these isokinetic indices must be assessed using multiple day-to-day trial protocols adequately to describe performance capacity. Composite indices such as the ratio of Knee flexion to extension PT and fatigue measurements offer considerably reduced reliability and a greater potential for misinterpretation. The reliability of knee extension indices generally exceeds that of flexion indices. Similar variability and reproducibility of responses were observed between men and women and between reciprocal contractions performed at angular velocities of 1.05 $rad \cdot s^{-1}$ and 3.14 $rad \cdot s^{-1}$.

Key words: Isokinetic contractions – Reliability – Leg muscle strength – Endurance – Gender difference

Introduction

Isokinetic dynamometers have become popular devices for studying dynamic muscle function in both clinical and research settings. A crucial aspect of research into muscle performance characteristics is the assessment of a reliable baseline score for the dependent variable under investigation. The fundamental question of how many trials to establish a true measure of a subject's isokinetic leg strength has been the subject of relatively few and methodologically diverse investigations. Based on a variability criterion of cumulative means of trials falling within one-quarter standard deviation of the grand mean of a series of intra-day trials, Sawhill et al. (1982) concluded that a minimum of four trials are necessary to produce stable isokinetic data in men using an Orthotron dynamometer. Other studies have reported the test-retest and single-measurement reliability of isokinetic knee extension and flexion peak torque to be generally greater than 0.95 for intra-day trials (Bohannon and Smith 1989; Feiring et al. 1990; Stratford et al. 1990). Of the small number of studies that have systematically investigated day-to-day reliability in isokinetic performance indices, Johnson and Siegel (1978) concluded that variability is greater for day-to-day testing (5.10%) than for intra-day trials (2.05%) and that day-to-day testing has a more adverse effect on measurement reliability coefficients, during investigation of gravity uncorrected knee extensor movements in women using a Cybex II dynamometer. This finding suggests that estimates of reliability based on intra-day measures alone may be underestimating the biological variability inherent in isokinetic leg strength and endurance test performance.

Peak torque (PT) is consistently favoured as a measure of isokinetic leg strength (Hislop and Perrine 1967; Rothstein et al. 1983, 1987; Burnie and Brodie 1986; Perrin et al. 1987; Kannus and Jarvinen 1989), referring to the single highest torque output of the joint produced by muscular contraction as the limb moves through a range of motion. However, there appears to be little standardisation over the number of contractions permitted to assess this index or whether contractions are unidirectional involving single muscle group or bidirectional (reciprocal) involving both agonist and antagonist muscle groups in continuous movements (Baltzopoulos and Brodie 1989). The latter mode of contraction is often preferred in clinical applications (Burdett and van

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Swearingen 1987). Average PT (APT) over several contractions is often used as an alternative index of isokinetic leg strength due to reported greater reliability (Johnson and Siegel 1978; Stratford et al. 1990). Few studies have reported the day-to-day variability and reliability of either composite strength indices such as the Knee flexion to extension PT ratio (PTR), which are considered important in the diagnosis of muscle imbalance (Kannus 1988), or of muscle endurance indices. The latter indices may have a greater tendency to be influenced by motivation artefacts and so be less reliable than measures of strength (Burdett and van Swearingen 1987).

The purpose of this study was to assess the day-to-day variability and measurement reliability of selected isokinetic knee extension-flexion strength and endurance indices.

Methods

Ten adult men [age 28.4 (3.9) years; height 1.78 (0.06) m; body mass 80.4 (8.0) kg; mean (SE)] and 8 adult women [age 27.5 (4.7) years; height 1.70 (0.07) m; body mass 63.5 (6.5) kg] gave their informed consent to participate in this study. No subject was receiving rehabilitation for injuries of the hip, knee, leg or ankle, or was symptomatic at the time of testing. All subjects were well motivated. Following a session in which the subjects were exposed to and familiarised with the test procedures, each returned to the laboratory to complete a sequence of three test sessions separated by a period of 5 days. Subjects were instructed to refrain from strenuous activity on the day before testing and testing days, and to maintain constant exercise levels throughout the experimental period. All subjects were tested as near to the same time of day as possible (± 1 h). Prior to testing, subjects completed a standardised warm-up consisting of 5 min cycle ergometry at an intensity of 88 W for men and 59 W for women and 5 min static stretching of the involved muscle groups. Subjects were then fixed to the testing apparatus (Lido 2.1, Loredan, Calif., USA). Subjects were seated with the angle between the back and seat of the dynamometer chair set at 1.57 rad and the angle between the chair and horizontal frame set at 0.26 rad to the horizontal. To localise the action to the proper muscle groups, subjects were securely strapped at the hip, waist, chest and shoulders with an additional restraint applied to the thigh proximal to thei involved joint. The dynamometer's lever arm was strapped to the involved leg just above the ankle joint. The lever length between the ankle cuff and the lever arm axis of rotation was standardised for each subject during day-to-day trials. The axis of rotation of the dynamometer was aligned midway between the lateral condyle of the tibia and the lateral epicondyle of the femur consistent with the anatomical axis of the knee joint. Automated compensation procedures for gravitational errors in recorded torques during maximal voluntary contraction (MVC) in the vertical plane were undertaken just prior to testing. The involved lower extremity of each subject was allowed to fall passively under gravity from a horizontal position at a standard angular velocity of 0.87 $rad \cdot s^{-1}$. Angle-specific torque data generated by the passive flexion of the leg and the weight of the input accessories (including the lever arm) were subsequently used routinely by the dynamometer's control software (Lidosoft 3.0S) to correct for the effects of gravity over the full range of movement. All instructions to subjects were given via standardised written instruction cards. Subjects were not given feedback of results until after the completion of the three trials.

Indices of isokinetic leg strength. Subjects were instructed to perform 4 submaximal and 2 maximal knee extension and flexion preparatory contractions. Subjects then completed a series of two randomly sequenced exercise bouts interspersed with 5 min passive recovery. These comprised 4 reciprocal MVC of the knee extensors and flexors of the preferred limb (defined as the leg used to kick a ball) in a continuous fashion, at angular velocities of 1.05 $rad \cdot s^{-1}$ ($60° \cdot s^{-1}$) and 3.14 $rad \cdot s^{-1}$ ($180° \cdot s^{-1}$). Gravity corrected indices of PT (PT_4), APT of 4 MVC (APT_4), and PTR (PTR_4) [(flexion peak torque/extension peak torque) $\times$ 100%] were calculated for each trial using the dynamometer's control software.

Indices of leg muscular endurance. The men subsequently performed an additional all-out exercise task consisting of 30 reciprocal MVC of the knee extensors and flexors of the preferred leg. The test was undertaken at a contraction velocity of 3.14 $rad \cdot s^{-1}$ with no rest between contractions. Subjects were verbally encouraged to exert MVC throughout their full range of motion. Gravity corrected PT (PT_{30}) (greatest torque recorded during any single contraction), APT over 30 contractions (APT_{30}), total work ($W_{tot,30}$) and an index of fatigue (FAT_{30}) were obtained during both extension and flexion movements. The latter index was automatically calculated using the dynamometer's control software. A least-squares regression was applied to the actual work done in all repetitions. The FAT_{30} was calculated as the ratio of the predicted work done in the last repetition compared to the first repetition and expressed as a percentage.

Test apparatus calibration. Prior to and repeatedly during testing the dynamic performance of the measurement instrument was subjected to a limited validity assessment using inert gravitational loading. Experimentally recorded dynamometer torques during the application of standard experimental torques (141.8 N and 202.4 N applied at a fixed distance of 0.505 m from the lever arm axis of rotation) were compared with expected resultant torques derived indirectly by mechanical analysis. Recorded PT with the lever arm horizontal demonstrated an overall mean (SE) technical error of 1.5 (0.6% and 1.8 (0.6%)) across a total of 9 and 14 calibrations at angular velocities of 1.05 $rad \cdot s^{-1}$ and 3.14 $rad \cdot s^{-1}$, respectively.

Statistical analyses. The selected dynamic muscle function indices were described using ordinary statistical procedures [mean (SE)]. Coefficient of variation (CV) corrected for small sample bias (Sokal and Rohlf 1981) was used to assess variability of indices across three trials. The CV was calculated according to the expression $(SE/mean) \cdot (1 + [1/4n])$ where n is the number of trials. Intra-class correlation coefficients and Spearman-Brown prediction formula indices (Winer 1981) were computed to describe single-measurement reliability and expected reliability of multiple measurements. Student's t-test was used to compare differences in reliability coefficients, where appropriate. Variability across three trials and absolute scores were compared using a 2 [muscle contraction velocity (1.05 $rad \cdot s^{-1}$ and 3.14 $rad \cdot s^{-1}$)] $\times$ 2 [contraction mode (extension and flexion)] $\times$ 5 (performance index) factorial repeated measures ANOVA with a between-subject factor of sex. The multivariate test statistic Pillai's Trace was used to examine this model. Performance indices were compared using a priori planned contrasts (Winer 1981). Statistical significance was accepted at $P < 0.05$. All statistical analyses were programmed using SPSS/PC+ (V3.1) software (SPSS, 1989).

Results

Tables 1 and 2 show mean (SE) scores for men and women respectively, for PT_4, APT_4 and PTR_4 at angular velocities of 1.05 $rad \cdot s^{-1}$ and 3.14 $rad \cdot s^{-1}$ during 4 reciprocal MVC of the knee extensor and flexor muscles. Table 3 shows group mean (SE) scores for men for PT_{30}, APT_{30}, $W_{tot,30}$ and FAT_{30} at an angular velocity of 3.14 $rad \cdot s^{-1}$ during 30 reciprocal MVC of the knee

Table 1. Mean (SE) peak torque, average peak torque, and peak torque ratio for men ($n=10$) in three trials of 4 reciprocal maximum voluntary contractions of the knee extensor and flexor muscles at angular velocities of 1.05 rad·s^{-1} and 3.14 rad·s^{-1}

	Peak torque (N·m)		Average peak torque (N·m)		Peak torque ratio (%)
	Extension	Flexion	Extension	Flexion	
Trial 1 (1.05 rad·s^{-1})	252 (33)	152 (30)	243 (32)	147 (32)	61 (6)
Trial 2 (1.05 rad·s^{-1})	250 (29)	156 (25)	239 (29)	150 (25)	62 (5)
Trial 3 (1.05 rad·s^{-1})	255 (33)	155 (24)	247 (34)	150 (24)	61 (6)
Trial 1 (3.14 rad·s^{-1})	177 (35)	124 (24)	167 (24)	114 (23)	71 (6)
Trial 2 (3.14 rad·s^{-1})	176 (24)	127 (20)	165 (22)	118 (18)	72 (4)
Trial 3 (3.14 rad·s^{-1})	182 (27)	128 (19)	173 (27)	122 (19)	70 (5)

Table 2. Mean (SE) peak torque, average peak torque, and peak torque ratio for women ($n=8$) in three trials of 4 reciprocal maximum voluntary contractions of the knee extensor and flexor muscles at angular velocities of 1.05 rad·s^{-1} and 3.14 rad·s^{-1}

	Peak torque (N·m)		Average peak torque (N·m)		Peak torque ratio (%)
	Extension	Flexion	Extension	Flexion	
Trial 1 (1.05 rad·s^{-1})	158 (11)	98 (10)	156 (11)	95 (9)	62 (4)
Trial 2 (1.05 rad·s^{-1})	156 (11)	92 (9)	153 (12)	90 (11)	59 (5)
Trial 3 (1.05 rad·s^{-1})	155 (13)	93 (9)	153 (13)	91 (9)	60 (5)
Trial 1 (3.14 rad·s^{-1})	103 (15)	72 (14)	97 (17)	70 (15)	70 (10)
Trial 2 (3.14 rad·s^{-1})	106 (16)	71 (11)	101 (17)	68 (12)	68 (13)
Trial 3 (3.14 rad·s^{-1})	98 (18)	66 (14)	94 (19)	63 (16)	68 (6)

Table 3. Mean (SE) peak torque, average peak torque, total work, and fatigue in three trials of 30 reciprocal maximum voluntary contractions of the knee extensor and flexor muscles for men ($n=10$) at an angular velocities of 3.14 rad·s^{-1}

	Peak torque (N·m)		Average peak torque (N·m)		Total work (J)		Fatigue (%)	
	Extension	Flexion	Extension	Flexion	Extension	Flexion	Extension	Flexion
Trial 1	173 (22)	123 (23)	135 (23)	96 (19)	4170 (660)	2780 (540)	60 (8)	53 (16)
Trial 2	170 (22)	125 (20)	135 (24)	100 (19)	3980 (710)	2690 (410)	58 (12)	51 (12)
Trial 3	176 (24)	125 (18)	140 (24)	102 (18)	3890 (580)	2550 (400)	58 (12)	51 (10)

Table 4. Percentage coefficient of variation (SE) for peak torque, average peak torque, and peak torque ratio for men ($n=10$) over three trials of 4 reciprocal maximum voluntary contractions of the knee extensor and flexor muscles at angular velocities of 1.05 rad·s^{-1} and 3.14 rad·s^{-1}

	Peak torque		Average peak torque		Peak torque ratio
	Extension	Flexion	Extension	flexion	
(1.05 rad·s^{-1})	2.9 (1.3)	5.0 (3.8)	2.7 (1.0)	5.6 (3.6)	4.5 (1.9)
(3.14 rad·s^{-1})	3.7 (3.2)	3.4 (2.8)	4.9 (3.5)	5.8 (3.5)	3.9 (3.5)

extensor and flexor muscles. No significant differences were observed between trials.

Variability of PT, APT and PTR strength indices

Tables 4 and 5 show mean CV for PT_4, APT_4 and PTR_4 for men and women, respectively, during 4 MVC at angular contraction velocities of 1.05 rad·s^{-1} and 3.14 rad·s^{-1}. Multivariate results using Pillai's Trace (V) as the test statistic suggest significant differences in CV scores between indices of isokinetic strength ($V=0.63$; $F_{[4,13]}=5.46$; $P<0.01$). The a priori contrasts suggest that increased variability of PT_4 and APT_4 flexion strength [5.5 (0.9)%] compared to extension strength [3.5 (0.9)%] ($t_{[64]}=2.73$; $P<0.015$) contributes most to the overall difference. Variability comparisons between PT_4, APT_4 and PTR_4 indices did not appear to contribute significantly to the overall difference. No significant differences in variability of strength indices were observed between men and women and between muscular contractions performed at angular velocities of 1.05 rad·s^{-1} and 3.14 rad·s^{-1}.

Variability of PT, APT, $W_{tot,30}$, and FAT_{30}

Table 6 shows mean CV for PT_{30}, APT_{30}, $W_{tot,30}$ and FAT_{30} during extension and flexion for men at angular contraction velocity of 3.14 rad·s^{-1}. Multivariate results using Pillai's Trace (V) as the test statistic suggest significant differences in CV scores between indices of

Table 5. Percentage coefficient of variation (SE) for peak torque, average peak torque, and peak torque ratio for women ($n=8$) over three trials of 4 reciprocal maximum voluntary contractions of the knee extensor and flexor muscles at angular velocities of 1.05 rad·s^{-1} and 3.14 rad·s^{-1}

	Peak torque		Average peak torque		Peak torque ratio
	Extension	Flexion	Extension	Flexion	
(1.05 rad·s^{-1})	2.5 (1.2)	5.8 (3.3)	2.9 (1.6)	6.2 (3.4)	5.2 (3.1)
(3.14 rad·s^{-1})	4.3 (4.4)	6.1 (2.6)	4.4 (2.8)	6.1 (2.6)	4.5 (2.1)

PT_{30}, APT_{30}, $W_{tot,30}$ and FAT_{30} ($V=0.69$; $F_{[3,27]}=5.26$; $P<0.05$). A priori contrasts suggest no significant differences in variability between FAT_{30} and $W_{tot,30}$ indices, which show a mean overall variability of 7.7%. Significantly greater variability for FAT_{30} and $W_{tot,30}$ compared to PT_{30} (3.3%) ($t_{[27]}=-3.78$; $P<0.005$), and for flexion indices (6.8%) compared to extension indices (4.9%) ($t_{[27]}=-2.86$; $P<0.02$) appears to contribute most to the observed overall differences in variability. Supplementary analyses suggest statistically similar variability between PT_4 and PT_{30} indices in these men. Additionally, no significant differences were observed be-

Table 6. Percentage coefficient of variation (SE) for peak torque, average peak torque, total work, and fatigue in three trials of 30 reciprocal maximum voluntary contractions of the knee extensor and flexor muscles for men ($n=10$) at an angular velocity of 3.14 rad·s^{-1}

Men:	Peak torque (N·m)		Average peak torque (N·m)		Total work (J)		Fatigue (%)	
	Extension	Flexion	Extension	Flexion	Extension	Flexion	Extension	Flexion
	2.4 (1.7)	4.3 (2.8)	2.7 (1.5)	4.0 (2.6)	4.9 (2.8)	6.6 (3.3)	7.2 (5.4)	12.0 (10.4)

Table 7. Single measurement reliability (intra-class correlation coefficients, R_I) and expected reliability of the mean of multiple measurements expressed in terms of the reliability of a single measurement (Spearman-Brown prediction formula) for peak torque, average peak torque, and peak torque ratio in three trials of 4 reciprocal maximum voluntary contractions of the knee extensor and flexor muscles for men ($n=10$) at angular velocities of 1.05 rad·s^{-1} and 3.14 rad·s^{-1}

		Peak torque		Average peak torque		Peak torque ratio
		Extension	Flexion	Extension	Flexion	
(1.05 rad·s^{-1})	1 trial (R_I)	0.964	0.940	0.971	0.938	0.781
	2 trials	0.982	0.969	0.985	0.968	0.877
	3 trials	0.988	0.979	0.990	0.978	0.914
	4 trials	0.991	0.984	0.992	0.984	0.934
(3.14 rad·s^{-1})	1 trial (R_I)	0.960	0.967	0.850	0.881	0.363
	2 trials	0.980	0.983	0.919	0.937	0.532
	3 trials	0.986	0.989	0.944	0.957	0.631
	4 trials	0.990	0.992	0.958	0.967	0.695

Table 8. Single measurement reliability (intra-class correlation coefficients, R_I) and expected reliability of the mean of multiple measurements expressed in terms of the reliability of a single measurement (Spearman-Brown prediction formula) for peak torque, average peak torque, and peak torque ratio in three trials of 4 reciprocal maximum voluntary contractions of the knee extensor and flexor muscles for women ($n=8$) at angular velocities of 1.05 rad·s^{-1} and 3.14 rad·s^{-1}

		Peak torque		Average peak torque		Peak torque ratio
		Extension	Flexion	Extension	Flexion	
(1.05 rad·s^{-1})	1 trial (R_I)	0.926	0.881	0.921	0.880	0.524
	2 trials	0.961	0.937	0.959	0.936	0.688
	3 trials	0.974	0.957	0.972	0.956	0.767
	4 trials	0.980	0.967	0.979	0.966	0.815
(3.14 rad·s^{-1})	1 trial (R_I)	0.976	0.948	0.980	0.949	0.911
	2 trials	0.988	0.973	0.989	0.974	0.953
	3 trials	0.992	0.982	0.993	0.982	0.968
	4 trials	0.994	0.986	0.995	0.987	0.976

Table 9. Single measurement reliability (intra-class correlation coefficients, R_I) and expected reliability of the mean of multiple measurements expressed in terms of the reliability of a single measurement (Spearman-Brown prediction formula) for peak torque, average peak torque, total work and fatigue in three trials of 30 reciprocal maximum voluntary contractions of the knee extensor and flexor muscles for men ($n=10$) at an angular velocity of 3.14 rad·s^{-1}

Men:	Peak torque (N·m)		Average peak torque (N·m)		Total work (J)		Fatigue (%)	
	Extension	Flexion	Extension	Flexion	Extension	Flexion	Extension	Flexion
1 Trial (R_I)	0.972	0.951	0.983	0.965	0.927	0.885	0.837	0.493
2 Trials	0.985	0.975	0.991	0.982	0.962	0.939	0.911	0.660
3 Trials	0.990	0.983	0.994	0.988	0.974	0.958	0.939	0.745
4 Trials	0.993	0.989	0.996	0.991	0.981	0.968	0.954	0.795

tween mean PT_4 over three trials [178 (28) N·m and 126 (21) N·m for extension and flexion, respectively] and mean PT_{30} over three trials [173 (22) N·m and 124 (20) N·m, respectively].

Single and multiple measurement reliability

Single measurement reliability (intra-class correlation coefficients, R_I) and expected reliability of the mean of multiple measurements expressed in terms of the reliability of a single measurement (Spearman-Brown prediction formula; Winer 1981) for PT_4, APT_4, and PTR_4 are shown in Tables 7 and 8 for one, two, three and four day-to-day trials in men and women, respectively. The corresponding reliability coefficients for PT_{30}, APT_{30}, $W_{tot,30}$ and FAT_{30} indices during 30 reciprocal MVC for men at 3.14 rad·s^{-1} are shown in Table 9.

PT, APT and PTR

Intra-class correlation coefficients for indices of PT_4, APT_4 and PTR_4 for men and women in this study population were not significantly different. Values for R_I for PT_4 in men and women ranged between 0.94 and 0.97 and 0.88 and 0.98, respectively. The single measurement reliability of PT_{30} in male subjects (0.95) was comparable to the shorter duration test (0.97). The R_I for ATP_4 showed a range of 0.85–0.97 for men and 0.88–0.98 for women. The R_I for APT_{30} for men (0.96–0.98) compares favourably to the latter reliability coefficients. Single measurement reliability for extension indices were greater than for flexion indices [0.95 (0.04) and 0.93 (0.03), respectively; $t_{[7]}=-4.5$; $P<0.01$).

Using an arbitrary criterion for acceptable reliability of >0.95, the results of Spearman-Brown predictions suggest that PT_4 requires data averaged over a minimum of three day-to-day trials to reliably describe this isokinetic leg strength characteristic. Corresponding data for APT_4 indices suggest a minimum of four day-to-day trials are required to achieve this prescribed level of reliability.

R_I for PTR_4 in men and women revealed low single measurement reliability, ranging between 0.36 and 0.91. These results imply that accurate discrimination of PTR_4 scores in this study's sample may not be possible on the basis of a single test. It is notable that generally PTR_4 data reliability is less than 0.95 even after four repeated day-to-day trials.

W_{tot} and fatigue

In the men R_I for $W_{tot,30}$ were 0.93 and 0.88 for extension and flexion, respectively. Acceptable reliability in this index (>0.95) may be obtained based on data averaged over a minimum of three day-to-day trials. By comparison single-measurement reliability for FAT_{30} was considerably lower (0.84 and 0.49 for extension and flexion, respectively). Results suggest that acceptable levels of reliability for the flexion FAT_{30} index may be very difficult to achieve in practice: 20 day-to-day trials would be required to exceed a reliability coefficient of 0.95.

Discussion

Variability in isokinetic dynamic muscle performance

Since statistical analyses revealed no differences in performance indices across trials, overall variability in performance can be assumed to represent random technological and biological sourced error. The CV for indices of isokinetic PT in this study (Tables 4, 5) compares favourably with those reported in other studies. The CV of scores ranging from 5.0% to 13.1% is reported for PT during knee extension for men measured over separate days (Thorstensson et al. 1976; Seger et al. 1988; Westing et al. 1988; Harries and Bassey 1990; Narici et al. 1991). Reported greater variability in knee flexion PT compared to extension PT for both males (Rochcongar et al. 1988) and females (Burdett and van Swearingen 1987) is consistent with the findings of this present study. It may be that inherently higher variability during knee flexion of the interaction of motoneuron recruitment, rate coding, temporal patterning and co-contraction phenomena (Milner-Brown et al. 1975; Enoka 1988) may underscore these findings for reciprocal contraction tests. Results showing statistically similar CV scores over three trials for PT_4, APT_4 and the composite index of PTR_4 during 4 reciprocal MVCs, together with PT_{30} and APT_{30} indicate that these indices can be assessed with equal measurement variability.

Isokinetic muscle endurance indices of $W_{tot,30}$ and FAT_{30} for mens can be assessed with significantly less variability during knee extension movements (4.9% and 7.2%, respectively) than knee flexion movements (6.6% and 12.0%, respectively). The latter endurance indices demonstrate significantly greater variability than PT_4 (2.4% and 4.3%, respectively). These trends are generally consistent with previous reports. Mathiassen (1989) reported the overall test-retest variability of work output decline (analogous to FAT_{30} in this study) as 6.9% for knee extensor muscles in men using a Cybex II dynamometer. During a 25 reciprocal contraction endurance test at 3.14 $rad \cdot s^{-1}$, Burdett and van Swearingen (1987) reported percent test-retest difference for indices of W_{tot} and fatigue during knee extension and flexion as 6.1% and 14.8%, and 9.8% and 18.2%, respectively. The ability to reproduce exactly the pattern of work output over repeated day-to-day trials therefore appears to be diminished compared to the reproducibility of the W_{tot} output. The latter trend may be due in part to an intrusion of conscious or unconscious work output pacing strategies as suspected for this and other exercise modalities during tests of similar duration (Burke et al. 1985; Perrin 1986). The inflated variability associated with the assessment of isokinetic endurance parameters may be explained by the problems of subjects having to sustain a higher degree of self-motivation to maximum effort throughout the 30 repetitions lasting some 40 s, compared to the relatively short duration of the 4 MVC strength assessment. The composite index of FAT_{30} in the knee flexor muscles may be particularly problematic in this respect, indicated by high variability and a considerable range of variability scores (5.6% to 20.5%).

Single-measurement reliability in isokinetic dynamic muscle performance

Intra-class correlation coefficients for PT_4 and APT_4 in men and women range between 0.85 and 0.98 for knee extension and 0.88–0.97 for knee flexion indices. Previous studies report a similar range for index reliability coefficients. Knapik et al. (1980) report R_I ranging from 0.94 to 0.95 for knee extension PT and 0.95–0.96 for knee flexion PT, at contraction velocities of 90 $rad \cdot s^{-1}$ and 3.14 $rad \cdot s^{-1}$. Montgomery et al. (1989) report somewhat lower average reliability coefficients for the same indices (0.88 and 0.79 for extension and flexion, respectively). Using the Cybex II dynamometer in both gravity uncorrected (Johnson and Siegel 1978) and gravity corrected modes (Bohannon and Smith 1989), R_I of 0.94–0.97 are reported for indices of knee extension PT at low to moderate velocities of contraction (0.52 $rad \cdot s^{-1}$–3.14 $rad \cdot s^{-1}$). Francis and Hoobler (1987) report the average single-measurement reliability of knee extensor and flexor PT using the Lido 2.0 as the test instrument as 0.85 for gravity uncorrected data. This is generally lower than the day-to-day single-measurement reliability reported for men in gravity uncorrected mode in this laboratory (0.91) (Gleeson and Mercer 1991).

Intra-class correlation coefficients for PT_{30}, APT_{30} and $W_{tot,30}$ during the endurance test of 30 MVCs for men (Table 6) were not dissimilar to those calculated for the shorter duration 4 MVC strength test at 3.14 $rad \cdot s^{-1}$, suggesting that on the basis of single-measurement reliability alone indices of strength and endurance can be assessed equally well from within the same composite test. The reliability of the W_{tot} index in this study (0.93 and 0.88 for extension and flexion, respectively) compares favourably to the mean R_I of less than 0.80 reported for the same endurance index by Montgomery et al. (1989) during three repeated trials, 2–4 days apart.

Results suggest that the composite indices of PTR_4 in men and women and FAT_{30} in men offer low single-measurement reliability. Similar conclusions were drawn for a comparable value of FAT ($R_I = 0.48$) over 25 reciprocal and continuous contractions by Burdett and van Swearingen (1987) measured at 3.14 $rad \cdot s^{-1}$.

Minimum number of day-to-day trials for the reliable description of isokinetic dynamic muscle performance

R_I results suggest that none of the typically used indices of isokinetic dynamic muscle function can be used unreservedly. In continuous reciprocal knee extension and flexion movements, predictions of the likely reliability of data associated with the mean of multiple trials suggest that the assessment of PT and APT capacities should be repeated over a minimum three and four day-to-day trials, respectively, to consistently achieve reliability acceptable for scientific research purposes (arbitrarily, >0.95). This finding is supported by other reports in the literature suggesting that a minimum of four trials are necessary to achieve stable isokinetic PT and APT data (Sawhill et al. 1982; Stratford et al. 1990). Relatively less reliability, $R_I > 0.80$, may be considered suitable for the clinical setting (Currier 1984; Burdett and van Swearingen 1987). Composite indices such as PTR may achieve acceptable research orientated reliability only after an extended series of day-to-day trials. Similarly, inherent difficulties of motivating subjects and patients to maximal voluntary effort during 30 contractions over 20 day-to-day trials to achieve acceptable reliability, may preclude the meaningful use of the knee flexion fatigue index in all but the most stringent research setting and highly self-motivated subjects.

Errors associated with single measurements

Another appropriate way of interpreting the reliability and utility of indices of isokinetic strength is to consider the standard error of a single measurement (Thomas and Nelson 1985) associated with selected indices. In this study population, based on a single visit to the laboratory, a given subject's true PT_4 could be estimated with an error of ±7.2% (95% confidence limits). This measure of error associated with true score assessment takes into account the measured single-measurement reliability for this index and the sample CV of approximately 14.5%. By contrast, the composite index of PTR_4, which has relatively low calculated single-measurement reliability, demonstrates up to ±13.5% error. Thus based on a single trial, this latter index would seem to offer only limited ability to discriminate between subjects and performance capacities. Such limited discrimination capacity may be sufficient in the clinical setting to identify gross dynamic muscle insufficiency. However such limitations may be totally unacceptable when attempting to interpret the effects of intervention conditioning in an elite strength athlete, whose performance levels may vary by only ±5% over the competitive season (unpublished data). The single trial assessment of knee flexion FAT_{30} in men is likely to be even more susceptible to misinterpretation (±22.8%).

The use of three day-to-day trials in the assessment of PT to enhance measurement reliability, for example, allows an individual's true performance capacity to be estimated with a more acceptable error of approximately ±2.8% and ±4.1% for knee extension and flexion, respectively (95% confidence limits). However, caution must be exercised in the extrapolation of reliability estimates from one experimental population to another. For example, reliability data reported by Johnson and Siegel (1978) for single-trial knee extension PT in a heterogeneous population of women (CV = 38.1%; $R_I = 0.94$), translates to a standard error of the estimate for a single measurement of ±18.6% (95% confidence limits). This is considerably greater than the error (±7.2%) associated with the relatively homogeneous sample of women in this study, despite a similar R_I. Further, for a given level of subject day-to-day variability in performance, the variance partitioning techniques used in the calculation of R_I are likely to identify inflated single measurement reliability estimates in heterogeneous populations.

Conclusions

On the basis of variability of performance over three trials, single measurement reliability and likely error in the estimation of the true performance capacity, results support the continued use of PT and APT as indices of isokinetic leg strength. Similarly, APT and W_{tot} should be the preferred indices of isokinetic leg endurance capacity in this or a similar population of adult mens. The reliability of performance indices derived from knee extension movements generally exceeds that of flexion indices during continuous reciprocal contractions. Men and women investigated in this study showed similar reproducibility responses. For scientific research purposes, frequently used indices of dynamic muscle function such as PT must be assessed using multiple day-to-day trial protocols to adequately describe isokinetic leg strength performance. In this respect, performance information from composite indices such as PTR and fatigue may not provide necessary scientific rigour. In men, the efficacy of using a composite strength and endurance test at 3.14 $rad \cdot s^{-1}$ is supported since PT can be assessed in the 4 MVC strength and the 30 MVC endurance tests with no significant differences between absolute values and with similar variability and reliability. Reliability studies involving greater than three repeat performance trials may be necessary to ascertain whether the plateau in performance observed in this study is a representative trend or whether it is indicative of an initial stage of a more complex accommodation response.

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