Time-of-day dependence of isokinetic leg strength and associated interday variability

J. P. Wyse BA, T. H. Mercer MSc and N. P. Gleeson MPhil

Exercise Science Laboratory, Division of Sport, Health and Exercise, School of Sciences, Staffordshire University, Stoke-on-Trent, UK

The purpose of this study was to assess the interday variability and time-of-day effects on selected isokinetic leg strength indices. Nine adult collegiate sportsmen (mean(s.e.) age 19.6(0.5) years; mean(s.e.) height 1.81(0.02) m; mean(s.e.) body mass 76.5(3.1) kg) completed a series of nine test sessions, organized so that each subject was tested three times within a day (08.00–09.00 hours; 13.00–14.00 hours; 18.00–19.30 hours), on three occasions, each separated by a minimum of 7 days. Gravity-corrected indices of extension peak torque (EPT), flexion peak torque (FPT), and the peak torque ratio (PTR), at contraction velocities of 1.05 rad s⁻¹ and 3.14 rad s⁻¹, were calculated for each subject using an isokinetic dynamometer. Two-way repeated measures analysis of variance of coefficient of variation (V%) scores revealed no significant differences in performance variability across within-subject factors of time-of-day and performance index ($P > 0.05$). Overall mean(s.e.) V% for scores across experimental conditions were 3.97(0.72)% at 1.05 rad s⁻¹ and 5.98(1.23)% at 3.14 rad s⁻¹, suggesting that similar levels of measurement error occur between 08.00–19.30 hours. One-way repeated measures analysis of variance of absolute strength indices (EPT, FPT and PTR) revealed that significantly higher scores were achieved during session 3 (18.00–19.30 hours), with mean(s.e.) values of 249.1(40.0) N m, 149.0(32.3) N m, 59.5(5.0)% at 1.05 rad s⁻¹, and 172.1(38.7) N m, 121.3(27.7) N m, 71.1(6.2)% at 3.14 rad s⁻¹, respectively ($P < 0.05$). This finding appears to be consistent with current knowledge about time-of-day effects on the assessment of muscular strength. Thus for stable and maximal values to be obtained during isokinetic leg testing, the use of multiple-trial protocols is recommended, with testing occurring as close to 18.00–19.30 hours as possible. In addition, the observed significant time-of-day effect suggests that appropriate comparison of maximal isokinetic leg strength can only be achieved based on data obtained within 30 min of the same time of day.

Keywords: Isokinetic leg strength, interday variability, time-of-day dependence, multiple-trial protocol

It is interesting to note that although elite athletes are tested for physiological attributes with increased regularity, many are assessed for isokinetic leg

strength on an annual basis, using one-trial protocols only. This latter observation may be due in part to both time and logistical constraints. Results from such research protocols have been reported frequently in the literature^{1–9}. However, recent work by Gleeson and Mercer¹⁰ has questioned the reliability of this testing approach. They endorse the preferred use of mean recorded values of multiple-trial protocols, with gravity-corrected data, to describe accurately and reliably the isokinetic leg strength characteristics of adult men and women.

The requirement for multiple-trial assessment protocols relates to a need to combat substantial variability associated with isokinetic strength assessments^{11–13}. The latter studies are characterized by coefficients of variation of up to 8.5% and 13.1% for intraday and interday trials, respectively. Intraday variability in isokinetic strength assessments may be driven, at least in part, by circadian rhythm. This is a category of biological rhythms which last approximately 24 h and which follow a sinusoidal response curve with optimal performance occurring in the late afternoon^{14–16}. In this way, isokinetic strength may be affected by the time of day at which the test occurs. Previous studies have suggested the existence of circadian rhythms in hand grip strength^{17–18}, and in leg and back strength as assessed by a spring-loaded dynamometer¹⁹. However, few studies have investigated the time-of-day dependence of either measured levels of isokinetic leg strength, or the variability of this physiological capacity. Such information would be of importance to both exercise scientists and clinicians, since it would facilitate the testing of an individual within an optimal time window in which muscular strength is maximal and subject to the lowest naturally occurring levels of performance variability. Therefore the purpose of this study was to assess selected time-of-day effects on both isokinetic leg strength and on associated interday variability.

Subjects and method

Nine adult collegiate sportsmen comprising four soccer players, two distance runners, one sprinter, one decathlete and one karate student (mean(s.e.) age 19.6(0.5) years; mean(s.e.) height 1.81(0.02) m; mean(s.e.) body mass 76.5(3.1) kg) gave their in-

Address for correspondence: Mr J. P. Wyse, Exercise Science Laboratory, Division of Sport, Health and Exercise, School of Sciences, Staffordshire University, Leek Road, Stoke-on-Trent ST4 2DF, UK

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formed consent to participate in this study. No subject had a history of injury to either knee.

Procedure

Following an initial familiarization session with the test procedure and equipment, subjects returned to the laboratory to be tested three times during one day, at the following times: 08.00–09.00 hours (session 1), 13.00–14.00 hours (session 2), 18.00–19.30 hours (session 3). This procedure was repeated on an additional two occasions, each separated by a minimum of 7 days. Subjects were tested as near to the same time of day as possible (within 30 min).

After the completion of a standardized warm-up (consisting of 5 min of cycle ergometry at an intensity of 88 W, and static stretching), subjects were seated on an isokinetic dynamometer (Lido Digital 2.1, Loredan, California, USA). The seat angle was set at 0.26 rad (15°) to the horizontal, with an angle of 1.57 rad (90°) between the back and the seat of the chair. The preferred limb was positioned with the anatomical axis of rotation of the knee (the lateral femoral condyle) aligned with the axis of rotation of the lever arm of the dynamometer. The lever arm was strapped to the involved leg, just above the ankle joint. Restraining straps were placed around the shoulders, chest and waist, with an additional restraint applied to the thigh (proximal to the knee joint), in order to stabilize body segments and prevent any extraneous body movement. The available range of motion was limited mechanically between 0 rad (knee fully extended) and 1.57 rad of knee flexion.

The effects of gravity during dynamic muscle contraction in the vertical plane were compensated for by the software package used with this dynamometer. This, as suggested by Nelson and Duncan²⁰, involved the calculation of the torque values of the limb-lever arm at each angle while falling passively. These values were automatically added to those measured during knee extension and subtracted from those during knee flexion in the test.

The dynamometer was then randomly set at a contraction velocity of either 1.05 rad s⁻¹ (60° s⁻¹) or 3.14 rad s⁻¹ (180° s⁻¹). At each test velocity four reciprocal nonmaximal contractions of the knee extensors and knee flexors were performed in preparation for the actual test. After resting passively for 1 min, subjects performed four reciprocal maximal voluntary contractions (MVCs) at the preset velocity. The results of this bout of dynamic muscular contraction were recorded. After a 5-min period of passive rest, the procedure (four nonmaximal contractions, 1 min rest, four MVCs) was repeated at the other test velocity.

Indices of isokinetic leg strength

Gravity-corrected indices of non-angle specific extension peak torque (EPT) and flexion peak torque (FPT), and the peak torque ratio (PTR) ((FPT/EPT) × 100%), at 1.05 rad s⁻¹ and 3.14 rad s⁻¹ were analysed separately. Peak torque was the highest recorded

value through the range of motion during the four MVCs. The arithmetic mean of three interday trials was used to describe these indices¹³.

Statistical analysis

The selected isokinetic muscle function indices were initially analysed by standard descriptive statistics (mean(s.e.)). Coefficient of variation (*V*%), corrected for small sample size bias²¹, was used to assess the variability of indices across trials at the different times of day. *V*% was calculated according to the expression ((s.e./mean) (1 + (1/4n)), where *n* is the number of trials. A two-way repeated measures analysis of variance of the *V*% scores was conducted to assess whether any significant differences in performance existed across within-subject factors of time of day and isokinetic strength index.

One-way repeated measures analyses of variance were conducted on the absolute group mean scores of all performance indices with *a priori* planned comparisons²². In these analyses, session 1 was compared with session 2, and the mean of sessions 1 and 2 was compared with session 3. Statistical significance was accepted at *P* < 0.05. All statistical analyses were programmed using SPSS/PC+ (Version 3.1; SPSS, Chicago, Illinois, USA) software.

Results

V% scores across the mean of the three testing sessions are presented in Table 1. Two-way repeated measures analysis of variance of the *V*% scores revealed no significant differences in performance across within-subject factors of time-of-day and isokinetic strength index (extension *versus* flexion).

The recorded indices of dynamic isokinetic muscle function, arithmetically averaged over the 3 days of testing, are displayed in Table 2. All indices attained during session 2 were greater than those from session 1, with the exception of PTR at 1.05 rad s⁻¹. However, the one-way repeated measures analysis of variance revealed that only FPT at 1.05 rad s⁻¹ was significantly greater during session 2 (*P* < 0.02). Results of the second planned comparison (of the mean of sessions 1 and 2 *versus* session 3) revealed that all indices were greater during the latter session, and that these differences were significant (*P* < 0.03).

Table 1. Variability of non-angle specific peak torque (EPT, FPT) and peak torque ratio indices: coefficient of variation scores (%)

Strength index	Session 1*	Session 2*	Session 3*
1.05 rad s ⁻¹			
EPT (Nm)	3.65(2.00)	2.42(0.78)	3.98(1.91)
FPT (Nm)	4.33(3.12)	3.93(3.15)	5.21(3.37)
PTR (%)	4.21(1.79)	4.14(2.44)	3.92(2.32)
3.14 rad s ⁻¹			
EPT (Nm)	4.66(2.54)	4.43(2.54)	4.43(3.02)
FPT (Nm)	8.04(5.56)	6.90(6.00)	4.85(2.70)
PTR (%)	5.47(3.98)	5.94(5.04)	7.63(4.73)

*Values are mean(s.e.); EPT, extension peak torque; FPT, flexion peak torque; PTR, peak torque ratio

Table 2. Non-angle specific peak torque (EPT, FPT) and peak torque ratio indices: group mean absolute values

Strength index	Session 1*	Session 2*	Session 3*
1.05 rad s ⁻¹			
EPT (Nm)	235.8(42.6)	241.9(36.1)	249.1(40.0) ⁺
FPT (Nm)	137.8(31.5)	141.3(33.4) ⁺	149.0(32.3) ⁺
PTR (%)	58.0(4.8)	57.8(6.7)	59.5(4.9) ⁺
3.14 rad s ⁻¹			
EPT (Nm)	162.7(36.6)	170.8(32.2)	172.1(38.7) ⁺
FPT (Nm)	106.7(30.5)	111.6(30.1)	121.3(27.7) ⁺
PTR (%)	65.0(8.9)	65.1(8.7)	71.1(6.2) ⁺

*Values are mean(s.e.); EPT, extension peak torque; FPT, flexion peak torque; PTR, peak torque ratio; ⁺, significant difference (analysis of variance; $P < 0.05$); ⁺, significant difference (analysis of variance; $P < 0.01$)

Discussion

The group mean absolute values of EPT and FPT, at both test velocities, are consistent with other findings reported in the literature^{1-2,4-7}. However, PTR scores were some 10% lower than those reported^{1-3,8-9}. This latter finding may be attributed to the fact that only in the present study were torque values corrected for the effects of gravity. The PTRs obtained in the gravity-uncorrected studies, which add gravitational forces to knee flexion and subtract it from knee extension, therefore represent artificially inflated PTRs, and it has been suggested that the results and conclusions of such studies must be treated with great caution²³.

Analysis of the data by means of one-way analyses of variance for day 1 to day 3 revealed no systematic learning effects across the days of testing. Thus, it would appear that the performance variability encountered in this study was due to technological and biological sources only.

Analysis of the data by means of one-way analyses of variance revealed no significant time-of-day variability differences between V% scores for all performance indices (EPT, FPT and PTR) at both test velocities. Overall mean(s.e.) V% scores across the experimental conditions were 3.97(0.72)% at 1.05 rad s⁻¹ and 5.98(1.23)% at 3.14 rad s⁻¹. These results compare favourably with those in the literature concerning the interday variability of dynamic isokinetic muscle function, which range from 5.1%¹² to 13.1%¹¹. The findings from this study suggest, therefore, that the interday variability of the selected isokinetic strength indices are not dependent on the time of the day at which testing is undertaken. Therefore, based on the criterion of the lowest occurring performance variability, single-trial assessments appear likely to be subject to similar levels of measurement error between 08.00 hours and 19.30 hours, and so testing is endorsed through this period. However, the level of interday V% suggests that individual and small groups of athletes should preferably be tested using multiple-trial day-to-day protocols to reduce measurement error and the potential for misinterpretation of scores¹³.

All absolute performance indices produced significantly greater scores during session 3 (18.00–19.30 hours) (Table 1). The percentage increases from sessions 1 and 2 to session 3 range from 2.76% (PTR at 1.05 rad s⁻¹) to 11.13% (FPT at 3.14 rad s⁻¹). This suggests that the measurement of isokinetic leg strength levels is time-of-day dependent, and this appears to be consistent with current knowledge about time-of-day effects on aspects of muscular strength¹⁷⁻¹⁹.

In conclusion, based on the criterion of maximal isokinetic leg strength, assessments should take place between 18.00 hours and 19.30 hours. In addition, the significant time-of-day effect revealed in this study suggests that, in both clinical and scientific settings, appropriate comparison of maximal isokinetic leg strength can only be achieved based on data obtained at the same time of day (allowing a margin of 30 min).

References

- Wyatt MP, Edwards AM. Comparisons of quadriceps and hamstrings torque values during isokinetic exercise. *Journal of Orthopaedic and Sports Physical Therapy* 1981; 3: 48–56.
- Morris A, Lussier L, Dooley G, Bell J. Hamstring/quadriceps ratio in middle distance and distance runners. *Physician and Sportsmedicine* 1983; 11: 71–7.
- Rankin JM, Thompson CB. Isokinetic evaluation of quadriceps and hamstrings function: normative data concerning body weight in sport. *Athletic Training* 1983; 18: 110–14.
- Oberg B, Ekstrand J, Moller M, Gilquist J. Muscle strength and flexibility in different positions of soccer players. *International Journal of Sports Medicine* 1984; 5: 213–16.
- Burnie J, Brodie DA. Isokinetic measurement in preadolescent males. *Int J Sports Med* 1986; 7: 205–9.
- Kannus P. Relationship between peak torque and total work in an isokinetic contraction of the medial collateral ligament insufficient knee. *Int J Sports Med* 1988; 9: 294–6.
- Rochcongar P, Morvan R, Jan J, Dassonville J, Belloit J. Isokinetic investigation of knee extensors and knee flexors in young French soccer players. *Int J Sports Med* 1988; 9: 448–50.
- Moore JR, Wade G. Prevention of anterior cruciate ligament injuries. *National Strength and Conditioning Association Journal* 1989; 11: 35–40.
- Read MTF, Bellamy MJ. Comparison of hamstring/quadriceps isokinetic strength ratios and power in tennis, squash and track athletes. *Br J Sports Med* 1990; 24: 178–82.
- Gleeson NP, Mercer TH. Intra-subject variability in isokinetic knee extension and flexion strength characteristics of adult males: a comparative examination of gravity-corrected and -uncorrected data. *J Sports Sci* 1991; 9: 415–16.
- Thorstensson A, Grimby G, Karlsson J. Force-velocity relations and fibre composition in human knee extensor muscles. *J Appl Physiol* 1976; 40: 12–16.
- Johnson J, Siegel D. Reliability of an isokinetic movement of the knee extensors. *Res Q Exerc Sport* 1978; 49: 88–90.
- Gleeson NP, Mercer TH. Reproducibility of isokinetic leg strength and endurance characteristics of adult men and women. *Eur J Appl Physiol* 1992; 65: 221–8.
- Armstrong LE. Desynchronisation of biological rhythms in athletes: jet lag. *National Strength and Conditioning Association Journal* 1988; 10: 68–70.
- Reilly T. Circadian rhythms and exercise. In: MacLeod D, Maughan R, Nimmo M, Reilly T, Williams C, eds. *Exercise: Benefits, Limits and Adaptations*. London, UK: E. and F. N. Spon, 1987: 346–64.
- Winget CM, DeRoshia CW, Holley DC. Circadian rhythms and athletic performance. *Med Sci Sports Exerc* 1985; 17: 498–516.
- Baxter C, Reilly T. Influence of time of day on all-out swimming. *Br J Sports Med* 1983; 17: 122–7.

- 18 Reilly T, Walsh TJ. Physiological, psychological and performance measures during an endurance record for five-a-side soccer. *Br J Sports Med* 1981; 15: 122-8.
- 19 Coldwells A, Atkinson G, Reilly T. The validity and reliability of back and leg dynamometry. *J Sports Sci* 1991; 9: 334.
- 20 Nelson S, Duncan P. Correction of isokinetic torque recordings for the effect of gravity. *Phys Ther* 1983; 63: 674-6.
- 21 Sokal R, Rohlf F. *Biometry*, 2nd ed. Oxford, UK: W. H. Freeman, 1981.
- 22 Winer BJ. *Statistical Principles in Experimental Design*, 2nd ed. New York, USA: McGraw-Hill, 1981.
- 23 Baltzopoulos V, Brodie DA. Isokinetic dynamometry; applications and limitations. *Sports Med* 1989; 8: 101-16.

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