Reliability of isokinetic torque measurements: A review of the literature

Julie E Nitschke

Recently there has been increased interest in the use of isokinetic exercise by physiotherapists both in scientific research and clinical practice. Isokinetic exercise can be used for the assessment of muscle performance and for the treatment of impaired muscle performance. Fundamental to the use of isokinetic exercise is the establishment of reliable test protocols for each joint tested to ensure that the isokinetic measurements obtained from the several commercially available isokinetic dynamometers can be reliably reproduced. This paper reviews the literature available on the test-retest reliability of isokinetic torque measurements.


Key words: Reproduceability of results; Exercise; Muscle contraction

The recent upsurge in the use of isokinetic dynamometers for the measurement of muscle performance by physiotherapists in both scientific research and clinical practice, has highlighted the need to establish the reliability of isokinetic measurements obtained from the several commercially available dynamometers. The appropriate application of reliable test protocols and correct interpretation of the data obtained, are fundamental for the collection of clinically meaningful and reliable measurements of muscle performance. This paper will endeavour to present (a) an understanding of the issues concerned with reliability of isokinetic torque measurements, (b) an outline of the most reliable test protocols established for the collection of isokinetic torque measurements, and (c) an indication of the current clinical limitations in the use of isokinetic dynamometers.

Isokinetic muscle action

An isokinetic muscle action is one where the speed of movement remains constant 'irrespective of the magnitude of the forces generated by the participating muscles' (Hislop and Perrine 1967). This type of muscle action allows the constant to be the angular velocity of the movement, and the variable to be the resistance offered by the dynamometer to accommodate the changing force exerted by the muscle. As a result, maximal muscle activation is possible at all points in the range of movement. This constitutes an objective measurement of muscle performance throughout its available range, and attempts to overcome the limitations of isotonic and isometric muscle actions (Hinson and Rosentswieg 1973).

The dynamometer and reliability

An isokinetic dynamometer is an electromechanical device that can measure the performance of an isokinetic muscle action in most major joints in the human body. The parameters that can be obtained about an isokinetic muscle action from a dynamometer include force (Newtons), torque (Newton.Meters), range of movement (degrees), angular velocity (degrees per second) and duration (seconds) of the muscle action. Torque can be defined as the turning effect of a force about an axis of rotation, and Moffroid et al (1969) state that it is the product of the force by its perpendicular distance from the axis of the lever arm. Measures of peak torque, average torque and angle specific torque are used clinically as objective values that are representative of the performance of the muscle group being tested. These measures will be discussed in this paper.

Measurement of isotonic and isometric muscle actions can be obtained from some of the dynamometers, and other measurements of muscle performance such as work and power can be calculated from the parameters obtained from an isokinetic muscle...
action. Discussion of these is outside the scope of this paper.

To obtain reliable measurements of anisokinetic muscle action from an isokinetic dynamometer, it is important to first ascertain that the operating systems of the dynamometer are reliable and valid, and second that the test protocols used for testing the individual muscle groups will ensure reliability of results obtained both within the same test session and between test sessions. Thus it is important to determine that the isokinetic torque values obtained from the equipment are a true representation of muscle performance rather than random fluctuations due to measurement error (Richman et al 1980).

Research which investigates the reliability of isokinetic measurements necessitates accurate and detailed documentation of the methodology for clinicians and other researchers to be able to replicate the reliability in their own work. Work that does not report this detail is of little value and therefore will not be analysed in this paper.

Factors which may affect the reliability of isokinetic torque measurements obtained when testing human subjects include body position and stabilisation, motor learning, muscle fatigue, whether the muscle actions are single, reciprocal or continuous, concentric or eccentric, the angular velocity tested, the range of movement tested, the starting forces, the damp settings employed, volume of commands, encouragement, eye contact and proximity of the researcher to the subject, to name a few. These issues will be discussed in relation to the most reliable test protocols established and documented in the literature for isokinetic torque measurements. Reliable test protocols have been established for the Kinetic Communicator Exercise System (KIN/COM), Cybex II and Biodex isokinetic dynamometers only, and the present discussion will concentrate on these three.

### Table 1.
**Details of the method for each investigation.**

<table>
<thead>
<tr>
<th>AUTHORS</th>
<th>YEAR</th>
<th>EQUIPT</th>
<th>JOINT</th>
<th>MOV'T</th>
<th>MUSCLE ACTION</th>
<th>POSN</th>
<th>ANGULAR VELOCITY (Deg/sec)</th>
<th>ROM (ROM ISOK.) (Degrees)</th>
<th>TEST DAYS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mawdsley &amp; Knapik</td>
<td>1982</td>
<td>Cybex II</td>
<td>Knee</td>
<td>E</td>
<td>Con</td>
<td>Sit</td>
<td>30</td>
<td>0-90 (PT)</td>
<td>3</td>
</tr>
<tr>
<td>Mawdsley &amp; Croft</td>
<td>1982</td>
<td>Cybex II</td>
<td>Knee</td>
<td>E</td>
<td>Con</td>
<td>Sit</td>
<td>30</td>
<td>* (*)</td>
<td>1</td>
</tr>
<tr>
<td>Molnar et al</td>
<td>1979</td>
<td>Cybex II</td>
<td>Many</td>
<td>E/F</td>
<td>Con</td>
<td>Many</td>
<td>30</td>
<td>0-90 (PT)</td>
<td>1</td>
</tr>
<tr>
<td>Stratford et al</td>
<td>1990</td>
<td>Cybex II</td>
<td>Knee</td>
<td>E</td>
<td>Con</td>
<td>*</td>
<td>60</td>
<td>0-Full F (PT)</td>
<td>1</td>
</tr>
<tr>
<td>Bohannon et al</td>
<td>1989</td>
<td>Cybex II</td>
<td>Knee</td>
<td>E</td>
<td>Con</td>
<td>Sit</td>
<td>60</td>
<td>* (30-45)</td>
<td>1</td>
</tr>
<tr>
<td>Johnson &amp; Siegel</td>
<td>1978</td>
<td>Cybex II</td>
<td>Knee</td>
<td>E</td>
<td>Con</td>
<td>Sit</td>
<td>180</td>
<td>0-90 (PT)</td>
<td>3</td>
</tr>
<tr>
<td>Burnett et al</td>
<td>1990</td>
<td>Cybex II</td>
<td>Hip</td>
<td>F/E</td>
<td>Con</td>
<td>Supine</td>
<td>30,90</td>
<td>F/E Full (PT)</td>
<td>2</td>
</tr>
<tr>
<td>Markhede et al</td>
<td>1980</td>
<td>Cybex II</td>
<td>Hip</td>
<td>F/E</td>
<td>Con</td>
<td>Supine</td>
<td>60</td>
<td>Full (*)</td>
<td>1</td>
</tr>
<tr>
<td>Karnofel et al</td>
<td>1989</td>
<td>Cybex II</td>
<td>Ankle</td>
<td>DF/PF</td>
<td>Con</td>
<td>Sit</td>
<td>60,120</td>
<td>Full ROM (PT)</td>
<td>3</td>
</tr>
<tr>
<td>Leslie et al</td>
<td>1990</td>
<td>Cybex II</td>
<td>Ankle</td>
<td>INV/EV</td>
<td>Con</td>
<td>*</td>
<td>30,120</td>
<td>* (PT)</td>
<td>2</td>
</tr>
<tr>
<td>Jackson et al</td>
<td>1987</td>
<td>KIN/COM</td>
<td>Knee</td>
<td>E/F</td>
<td>Con/Ecc</td>
<td>*</td>
<td>50</td>
<td>80 (*)</td>
<td>1</td>
</tr>
<tr>
<td>Harding et al</td>
<td>1988</td>
<td>KIN/COM</td>
<td>Knee</td>
<td>E/F</td>
<td>Con</td>
<td>Sit</td>
<td>60</td>
<td>0-90 (10-80)</td>
<td>2</td>
</tr>
<tr>
<td>White &amp; Protas</td>
<td>1985</td>
<td>KIN/COM</td>
<td>Knee</td>
<td>E</td>
<td>Con</td>
<td>*</td>
<td>60</td>
<td>* (PT)</td>
<td>3</td>
</tr>
<tr>
<td>Kramer</td>
<td>1990</td>
<td>KIN/COM</td>
<td>Knee</td>
<td>F/E</td>
<td>Con/Ecc</td>
<td>Sit</td>
<td>45,90</td>
<td>0-100 (10-90)</td>
<td>3</td>
</tr>
<tr>
<td>Tredinnick et al</td>
<td>1988</td>
<td>KIN/COM</td>
<td>Knee</td>
<td>E</td>
<td>Con/Ecc</td>
<td>Supine</td>
<td>60,10</td>
<td>10-90 (PT)</td>
<td>2</td>
</tr>
<tr>
<td>Vysse &amp; Kramer</td>
<td>1990</td>
<td>KIN/COM</td>
<td>Elbow</td>
<td>F</td>
<td>Con/Ecc</td>
<td>Supine</td>
<td>60,150</td>
<td>120,180</td>
<td>3</td>
</tr>
<tr>
<td>Griffin</td>
<td>1987</td>
<td>KIN/COM</td>
<td>Elbow</td>
<td>F</td>
<td>Con/Ecc</td>
<td>Supine</td>
<td>30,120</td>
<td>40-120 (PT)</td>
<td>1</td>
</tr>
<tr>
<td>Feiring et al</td>
<td>1990</td>
<td>Biodex</td>
<td>Knee</td>
<td>E/F</td>
<td>Con</td>
<td>Sit</td>
<td>60,180</td>
<td>0-100 (PT)</td>
<td>2</td>
</tr>
<tr>
<td>Montgomery et al</td>
<td>1989</td>
<td>Biodex</td>
<td>Knee</td>
<td>E/F</td>
<td>Con</td>
<td>Sit</td>
<td>90, 150,210</td>
<td>270,330</td>
<td>3</td>
</tr>
</tbody>
</table>
Reliable test protocols

To examine the reliability of the test protocols for isokinetic torque measurements, the protocols for each dynamometer will be discussed separately. The best protocols in the literature will be outlined and those that do not provide clinically useful information will be only briefly referred to with reasons why they are not useful.

Kinetic Communicator Exercise System (KIN/COM)

The KIN/COM has four modes of exercise, isokinetic (concentric and eccentric), isometric, isotonic and passive which can be tested through a range of angular velocities between 0-210°/s (Malone 1988). The reliability of the operating systems of one KIN/COM was established by Farrell and Richards (1986). If the machines are calibrated correctly each KIN/COM should produce the same values for any given subject, however this has not been verified. Hanten and Lang (1988) confirmed the reliability of repeated measurements of torque from the KIN/COM using inert weights by comparing obtained torque, work and power values to predicted torque, work and power values. These studies validate the KIN/COM for use as a measurement tool for the evaluation of muscle performance, but do not establish test-retest reliability of isokinetic measurements for the individual muscle groups.

Knee

The most reliable and well documented test protocol found in the literature for the knee on the KIN/COM, was that of Harding et al (1988), who established a reliable reciprocal test protocol for concentric knee flexion and extension at an angular velocity of 60°/s. Other investigations of the reliability of isokinetic torque measurements for the knee on the KIN/COM have either been poorly performed or poorly documented (Jackson et al 1987, White and Protas 1985), or some omissions in the data analysis have rendered the clinical applicability of the results questionable and the real worth of the

<table>
<thead>
<tr>
<th>WARMUP REST BETWEEN (s=submax)</th>
<th>REST BETWEEN</th>
<th>TRIALS REST BETWEEN</th>
<th>CONTINUOUS</th>
<th>ISOKIN</th>
<th>DAMP SETTING</th>
</tr>
</thead>
<tbody>
<tr>
<td>(s=submax)</td>
<td>W/U &amp; TRIALS</td>
<td>INTERVAL</td>
<td>ANG VEL</td>
<td>CYCLES</td>
<td>CORRECTION</td>
</tr>
<tr>
<td>(Seconds)</td>
<td>(Seconds)</td>
<td>(Seconds)</td>
<td>(Seconds)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>*</td>
<td>6m</td>
<td>60</td>
<td>-</td>
<td>No</td>
</tr>
<tr>
<td>3s or 0</td>
<td>60s</td>
<td>6m</td>
<td>60</td>
<td>-</td>
<td>No</td>
</tr>
<tr>
<td>*</td>
<td>*</td>
<td>3m</td>
<td>*</td>
<td>*</td>
<td>No</td>
</tr>
<tr>
<td>3s,1m</td>
<td>120s</td>
<td>5m</td>
<td>0&amp;30</td>
<td>-</td>
<td>Yes</td>
</tr>
<tr>
<td>2s,1m</td>
<td>180s</td>
<td>4m</td>
<td>30</td>
<td>-</td>
<td>No</td>
</tr>
<tr>
<td>3s</td>
<td>*</td>
<td>6m</td>
<td>20</td>
<td>-</td>
<td>No</td>
</tr>
<tr>
<td>2-3s</td>
<td>*</td>
<td>4m</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>3s,3m</td>
<td>30s</td>
<td>6m</td>
<td>0</td>
<td>*</td>
<td>Yes</td>
</tr>
<tr>
<td>3s,3m</td>
<td>60s</td>
<td>5m</td>
<td>0</td>
<td>*</td>
<td>Yes</td>
</tr>
<tr>
<td>*</td>
<td>*</td>
<td>3m</td>
<td>*</td>
<td>*</td>
<td>No</td>
</tr>
<tr>
<td>4s</td>
<td>120s</td>
<td>6m</td>
<td>5</td>
<td>-</td>
<td>Yes</td>
</tr>
<tr>
<td>*</td>
<td>*</td>
<td>6m</td>
<td>*</td>
<td>*</td>
<td>No</td>
</tr>
<tr>
<td>3s,1m</td>
<td>120s</td>
<td>3m</td>
<td>0</td>
<td>0</td>
<td>No</td>
</tr>
<tr>
<td>4s,1m</td>
<td>120s</td>
<td>3m</td>
<td>5</td>
<td>180s</td>
<td>No</td>
</tr>
<tr>
<td>3s,1m</td>
<td>*</td>
<td>2m</td>
<td>30</td>
<td>180s</td>
<td>No</td>
</tr>
<tr>
<td>5s,1m</td>
<td>120s</td>
<td>3m</td>
<td>0</td>
<td>180s</td>
<td>No</td>
</tr>
<tr>
<td>2s,2-3m</td>
<td>*</td>
<td>5m</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>2s</td>
<td>*</td>
<td>5m</td>
<td>0</td>
<td>60s</td>
<td>Yes</td>
</tr>
</tbody>
</table>

F = Flexion  Con = Concentric
E = Extension  Ecc = Eccentric
AB = Abduction  AT = Average Torque
AD = Adduction  PT = Peak Torque
INV = Inversion  NA = Not Applicable
EV = Eversion  *= Not Stated
conclusions unclear (Kramer 1990, Tredinnick and Duncan 1988).

Harding et al (1988) established the test-retest reliability of a reciprocal test protocol for concentric knee flexion and extension at an angular velocity of 60°/s. The sample consisted of 14 healthy female subjects with no prior experience with the isokinetic testing apparatus. Their method was recorded in detail and is identified in Table 1. The minimum force required to initiate knee flexion was 80 Newtons (80N) and for extension 20N, but the reasons given for this choice were not indicated. Few studies have investigated the effect of different starting forces (static preload) on isokinetic torque production on either the Cybex II (Gransberg and Knutsson 1983) or the KIN/COM (Jensen et al 1991). Jensen et al (1991) demonstrated that high starting forces (75 per cent of maximum voluntary isometric contraction) for the knee extensors both concentrically and eccentrically at 90°/s, resulted in a different torque curve shape and significantly different torque values in the first 15 and 20 degrees of movement respectively when compared to a low starting force (50N). Average torque values were significantly different for the low and high starting forces while peak torque values did not differ significantly. Selection of starting forces at present appears to be random, and therefore further research is required to support the choice of particular starting forces to determine both the effect of different starting forces upon torque production, and the optimum starting forces for particular protocols for each of the muscle groups tested. Although Harding et al (1990) tested knee extension and flexion through 90 degrees of motion, they analysed only the peak and average torque through a range from 10 to 80 degrees. This is the range of true isokinetic movement (constant angular velocity) which correctly excludes the acceleration and deceleration portions of the torque curve. Measurements of peak and average torque and peak torque angle were recorded, and the means of these values were calculated as the criterion score. This test protocol was found to be highly reliable for peak and average torque both intra and inter-session for knee flexion and extension (Intraclass correlation coefficients (ICC) all between R=0.93 to 0.95). Harding et al (1990) cite an overall R value for each of these measures but it is not clear how this was calculated or its clinical interpretation. Peak torque angle was reliable within each test session but not between sessions. The results reported also demonstrated that there was greater measurement error between test sessions on separate days than within a single session. This illustrates the importance of calculation of the standard error of the measurement (SEM) and 95 per cent confidence intervals for peak and average torque at both test sessions. The SEM and 95 per cent confidence intervals enable the user of this protocol to establish that the difference in torque values between the two test sessions represents an actual change in the muscle performance rather than measurement error. This study presents a well designed and well documented investigation which renders this reciprocal test protocol reliable and useful in clinical terms when implemented using the same method, angular velocity and sample.

The issue of selection of an appropriate criterion score for the measurement of an isokinetic muscle action is one that would confront most physiotherapists using isokinetic dynamometers, and warrants some discussion here. The two options available are to choose either the single highest torque score of several muscle actions (trials), or the mean value of these muscle actions as Harding et al (1990) chose to do. If the torque scores do not show a systematic error, (ie a systematic trend over all the scores for each individual subject), then use of the mean of all trials is an appropriate measure (Kroll 1967). If there is a trend effect in the torque scores, choice of the single highest torque score may be appropriate (Kroll 1967). However, the researcher or clinician should consider that the selection of a test protocol that is free of systematic error (trend effect) will reduce the amount of error variance due to the trials (Kroll 1967). Failure to do so may constitute the difference between a reliable and unreliable test protocol (Griffin 1987), or reduce the degree of reliability (Stratford 1990). As a result each physiotherapist should closely examine their data before deciding on the most appropriate criterion measure for any particular test protocol. Another investigation of the test-retest reliability of knee movements on the KIN/COM worth reporting was that by Tredinnick and Duncan (1988). Although their method was well documented, inadequate analysis of the results rendered the interpretation and conclusions incomplete. Tredinnick and Duncan (1988) assessed the test-retest reliability of continuous cycles of isokinetic concentric and eccentric knee extensor peak torque at 60°/s, 120°/s and 180°/s on two separate occasions. High inter-session reliability was evident only with concentric extension at 120°/s (R=0.97) and 60°/s (R=0.89). Details of the methods used were clearly reported and can be found in Table 1. The omission of information about whether or not gravity correction of the data was performed should not affect reliability. This is because correcting for gravity is a constant and therefore as long as data that has been gravity corrected are not compared to data that has not been gravity corrected, the conclusions about reliability will still be accurate. Mean peak torque values for the three concentric and eccentric repetitions at each test session were used as the criterion measure, and ICC's for inter-session reliability were calculated. Omission of the analysis of variance (ANOVA) in the reporting and discussion of these results meant that the source of measurement error was not identified. It is therefore open to speculation whether the lower reliability coefficients at 180°/s for concentric and eccentric knee extension (R=0.75 and 0.84 respectively) and at 60°/s for eccentric
knee extension (R=0.47), were due to the angular velocity, test day, trials, muscle action or other variables. Confidence intervals for the ICCs were not cited. Certainly concentric peak torque at 120°/s and 60°/s for the knee extensors was reliable inter-session within the limitations of this study, but utilisation of this protocol would require caution without further analysis of the results obtained.

Kramer (1990) investigated the reliability of continuous cycles of isokinetic concentric and eccentric knee flexion and extension for measures of peak and average torque at 45°/s and 90°/s. However this author also did not report the SEM and 95 per cent confidence intervals. The method is outlined in Table 1. Although inter-session ICCs ranged from 0.79 to 0.91 for peak torque and 0.75 to 0.88 for average torque, ICCs alone without the SEM and 95 per cent confidence intervals do not give an indication of the magnitude of the variance due to measurement error. This information is important to be able to identify a change in muscle performance between sessions. The 95 per cent confidence interval is in the original units of measurement (torque in Nm) which allows for direct interpretation of any change in the torque scores between test sessions. An ICC alone does not yield this information, and hence without further reporting of SEM and 95 per cent confidence intervals, this study is of little clinical value.

Several other investigations of the reliability of isokinetic torque measurements of the knee on the KIN/COM (Jackson et al 1987 and White and Protas 1985) will not be discussed because inadequate documentation of the methods used, results and conclusions renders replication of these studies impossible. The omissions in the methodologies are outlined in Table 1.

Elbow
Two studies were located that addressed the reliability of isokinetic concentric and eccentric elbow flexion (Griffin 1987, Vyse and Kramer 1990). However each of these studies used different angular velocities. No other investigations of the reliability of elbow movements on the KIN/COM were found.

Griffin (1987) examined the intra-session test-retest reliability of concentric and eccentric elbow flexion at 30°/s and 120°/s. Details of the method were well documented and are shown in Table 1. Several points worth noting are (i) the selection of a starting force of 20N with no reasons for this choice given, (ii) the alignment of ‘the axis of rotation of the dynamometer with the elbow joint’ does not clearly state which anatomical landmark was aligned with the dynamometer, and (iii) the sequence of always testing the angular velocities from slow to fast to allow motor learning to occur has not been substantiated in the literature. Griffin’s (1987) choice of criterion score was the single highest peak torque score of the three maximal concentric and eccentric muscle actions. However Griffin (1987) did not first ascertain whether there was a systematic trend in the torque scores to confirm that this was the appropriate choice of criterion measure (Kroll 1967). ICCs were calculated as an index of reliability and an ICC of 0.9 was selected by the author as the lower limit for acceptable reliability. No reasons were given for this choice. By Griffin’s (1987) own classification, the protocol was not reliable. However, the ICCs ranged from R=0.72 for concentric flexion at 120°/s to R=0.83 for concentric flexion at 30°/s, which indicates moderate reliability (Currier 1984) for all but eccentric flexion at 120°/s. SEM and 95 per cent confidence intervals were not reported which makes interpretation of these ICCs limited and not clinically useful. A number of factors may have contributed to the measurement error associated with this study, some of which were identified by the author. These included muscle fatigue due to the absence of an inter-trial rest interval and/or the large number of warmup trials (five submaximal and one maximal), potentiation of concentric muscle actions when preceded by an eccentric muscle action (Komi 1986), poor stabilisation of the subjects during the test procedure, and the subjects lack of familiarity with the test procedure. Other factors which may have contributed to measurement error that the author did not identify were the element of bias which may have been introduced by always testing the angular velocities from slow to fast, and the use of the single highest torque score as the criterion measure. The mean of the three concentric and the mean of the three eccentric torque scores may have been a more appropriate choice of criterion measure. Griffin’s (1987) protocol does not represent an optimum or clinically useful tool for testing the elbow flexors either concentrically or eccentrically.

The lower reliability of eccentric muscle actions both at 30°/s and 120°/s compared to concentric muscle actions raises the issue of whether muscle fatigue with eccentric muscle actions is greater than concentric muscle actions with a protocol of consecutive muscle actions. Komi and Ruskol (1974) demonstrated that the fatigue which occurs with consecutive isokinetic eccentric elbow flexion was greater than that of concentric elbow flexion at 40°/s. Komi and Viitasalo (1977) demonstrated the same with the knee extensors. More recent work by Tesch et al (1990) with a different protocol demonstrated that isokinetic eccentric knee extension showed no fatigue with repeated muscle action at 180°/s while concentric knee extension did. These studies suggest that the variable results evident in studies of muscle fatigue with continuous muscle actions could be due to a number of factors. These may be either that different experimental protocols produce different results in relation to muscle fatigue (this is a problem that is also encountered widely throughout the literature on reliability of isokinetic torque measurements), or that the fatigue of the elbow flexors at higher angular velocities is different to the knee extensors. Nevertheless the conflicting findings of these studies make it difficult to draw conclusions about the fatigue of concentric versus
eccentric muscle actions in either the upper or lower limb.

Vyse and Kramer (1990) established the reliability of continuous activation cycles of concentric and eccentric elbow flexion at angular velocities of 60°/s and 150°/s. Unlike Griffin (1987), they inserted a 30 second rest interval between each cycle but no rest interval between the concentric and eccentric action within each cycle. Details of their method were documented and are outlined in Table 1. One omission was a record of whether there was a rest interval between the warmup repetitions and the trials. The choice of a starting force of 20N was justified with the explanation that it was the highest threshold force that allowed all subjects to activate the dynamometer arm through flexion. The process by which this was determined is unclear, and as stated previously this information has not been investigated or documented for the upper limb. Reference to the lateral epicondyle of the elbow as being the anatomic axis of the elbow is incorrect (London 1981, Morrey and Chao 1976, Youm et al 1979). However, the issue of importance is to consistently align the elbow with the same landmark, and that this should be as close as possible to the axis of rotation of the elbow joint.

Vyse and Kramer (1990) tested through a range of 120 degrees, but calculated the peak and average torque between 60 and 100 degrees. The reasons given for this procedure were (i) that this was the most likely range in which to locate peak torque, (ii) it was likely to be the most functionally important range, and (iii) that it would exclude impact artefacts. Clinicians and researchers should remember that it is important to analyse the range of movement through which angular velocity is constant for the accurate evaluation and interpretation of measurements of isokinetic muscle performance. Vyse and Kramer (1990) also examined the difference in torque scores when the cycles were reversed, (ie concentric/eccentric and eccentric/concentric), and found that concentric peak and average torques that were preceded by eccentric peak torques were higher than the reverse and that eccentric peak and average torques were lower when preceded by a concentric muscle action. Reliability for peak and average torque for concentric and eccentric muscle actions was high (R=0.90 to R=0.97) but the SEM and confidence intervals for these torque values were not reported. This test protocol represents a reliable method for testing concentric and eccentric elbow flexion intra-session with continuous activation cycles at 60°/s and 150°/s. However, the sequence of testing concentric and eccentric muscle actions should remain consistent.

Several salient points to note about this protocol are: (a) that accurate interpretation of any data would be difficult without 95 per cent confidence intervals because there is no indication of the magnitude of the error variance, and (b) that inter-session reliability has not been determined with this protocol. This test protocol should be used with caution, and the necessary further calculations should be undertaken to provide clinically meaningful data.

No literature was located that investigated the test-retest reliability of isokinetic torque measurements on the KIN/COM for any other joint.

Cybex I and II

The Cybex I was the first electromechanical dynamometer marketed commercially and Moffroid et al (1969) were the first to investigate the test-retest reliability of the measurement systems of this dynamometer. They established that the obtained to predicted values for torque, work, range of movement, power and speed were reliable under test-retest conditions using inert weights. Reliability in its application to human subjects was not addressed, and any reference to this study as evidence for reliability of the Cybex II is not appropriate (Mayhew and Rothstein, 1985).

The Cybex II system has two modes of exercise, isokinetic (concentric only) and isometric, and has a range of angular velocities from 0 to 300°/s (Malone 1988). Moroz and Sale (1985) examined the reliability of the torque transducer of the Cybex II in a study which was poorly documented, and found that the Cybex II was a highly linear measuring device that overpredicted torque output by one to two per cent throughout the three speeds and torque ranges that were tested on the knee and arm. Further investigation through other speeds as well as other output measures of the Cybex II, (eg range of movement, speed of lever arm etc) would be necessary to validate this equipment fully. Bemben et al (1988) examined the validity of the Cybex II and analog recorder system and found that it measured angular velocity to within 5 per cent of the target speed, and that the low damp settings (one to three) led to inaccurate peak torque values at lower angular velocities. Damp settings on the Cybex II were introduced in an attempt to control the torque overshoot observed at the beginning of the torque curve, but in themselves create certain artefacts (Gransberg and Knutsson 1983). Further discussion of damp is outside the scope of this paper, except that clinicians and researchers should record the damp setting that they have used so that their method can be replicated.

Knee

The most reliable test protocols for knee movements on the Cybex II were those established by Johnson and Siegel (1978), Bohannon and Smith (1989) and Stratford et al (1990).

Johnson and Siegel (1978) established the test-retest reliability of isokinetic concentric knee extension on the Cybex II at an angular velocity of 180°/s. This investigation was reasonably well documented and information about their method can be seen in Table 1. Important omissions were the damp setting used and the rest intervals between warmup and trial repetitions. A high test-retest reliability for isokinetic peak torque was obtained for the mean of the last
three sub-maximal warmup trials followed by six maximal trials each separated by a 20 second rest interval. As with all the previous studies the reasons for the selection of this particular warmup were absent. The results revealed a significant linear trend as a consequence of the first three trials each day. Johnson and Siegel (1978) therefore suggested that an average of three sub-maximal trials followed by three maximal trials is essential for stable measurements at 180°/s. While clinicians and researchers can regard Johnson and Siegel’s (1978) test protocol as reliable both intra and inter-session, no confidence intervals were cited that would make this protocol clinically meaningful. A logical progression of this study would be to investigate the reliability of this test protocol at other angular velocities for both knee extension and flexion, however this remains to be done.

The issue of the inclusion and type of warmup necessary prior to isokinetic test protocols warrants further discussion here. The only other investigation that addressed the number of warmup repetitions required for any test protocols were those of Mawdsley and Knapik (1982) and Mawdsley and Croft (1982) on the Cybex II. In contrast to Johnson and Siegel (1978) these authors demonstrated that a warmup of one maximal trial was necessary for inexperienced subjects performing knee extension at 30°/s. It was apparent also that no warmup was necessary for experienced subjects using the same protocol. One explanation for the different results may be that knee extension at higher angular velocities may be a more complicated task that requires more trials to learn than the same task at lower angular velocities. It is also difficult to directly compare the results from investigations that have utilised different test protocols. Further research is required to establish whether a warmup is necessary prior to isokinetic testing protocols. Similarly the quantity and type of warmup required for each protocol, angular velocity, muscle group and movement requires investigation.

Bohannon and Smith (1989) established the intra-session reliability of angle specific knee extension torque measurements also at an angular velocity of 60°/s. They measured isokinetic torque at two points in the range of movement, 30 and 45 degrees, over four repetitions each separated by a 30 second rest interval. The rationale provided for the choice of this protocol was to remove the artefacts associated with the use of a rest interval on isokinetic torque measurements. Clinicians and researchers can consider this test protocol reliable but only at 60°/s and within the same test session. Any clinician or researcher utilising this protocol would need to calculate confidence intervals for meaningful interpretation of their data. Further research would be required to establish inter-session reliability and reliability at other angular velocities with this protocol.

Stratford et al (1990) established the reliability of reciprocal concentric knee flexion and extension at 60°/s when they investigated the effect of an intertrial rest interval on isokinetic thigh muscle torque. They also determined that the most reliable method of examination of the data was to average all trials rather than use the single highest peak torque score. This fact reinforces the theory outlined earlier in this paper. Details of their method were reported (Table 1), however information about subject position, which is fundamental for the replication of this test protocol, were omitted. High reliability was obtained for flexion and extension both with a protocol which included a 30 second rest interval between each reciprocal cycle, and one which had no rest interval between each cycle (R’s from 0.92 to 0.99). Reliability was lower when the single highest torque score was taken as the criterion measure compared to the mean of all trials (as outlined by Kroll 1967), however ICCs were still above 0.92. This well designed and analysed investigation yields a reliable reciprocal test protocol for concentric knee flexion and extension at 60°/s on the Cybex II, either with or without a rest interval between cycles. The clinician or researcher should note that a rest interval between the reciprocal cycles with this test protocol will produce optimum reliability at this angular velocity. In addition, the standard error of measurement and confidence intervals demonstrate that the error associated with the no rest interval group was larger. Clinically this means that the protocol with the rest interval requires less deviation of the torque scores to detect a change in the performance of the muscle.

One investigation was located that attempted to determine whether there was a change in peak torque of the knee extensors over three test sessions two weeks apart (Mawdsley and Knapik 1982). Despite finding that there was no significant difference between peak torque scores measured two weeks apart over six weeks, this study does not directly address reliability. Details of the method are reported in Table 1, but use of this study as evidence of reliability is inappropriate.

Several other investigations in the literature examined the reliability of isokinetic torque measurements of knee movements on the Cybex II (Little and Sinning 1985, Molnar et al 1979), but lack of information about the method, results and conclusions make them of little use.

Hip
Two studies were found that addressed the test-retest reliability of hip movements (Burnett et al 1990, Markhede and Grimby 1980), both
From Page 131

using the Cybex II isokinetic dynamometer. The investigation by Markheide et al (1980) is not clinically useful because of the significant omissions in the reporting of the method of the study (see Table 1). Burnett et al (1990) demonstrated low reliability for hip flexion/extension and abduction/adduction at two angular velocities.

**Ankle**

The reliability of isokinetic torque measurements of ankle movements has been investigated by Karnofel et al (1989) and Leslie et al (1990) on the Cybex II. A number of other studies have endeavoured to obtain normative data for ankle movements on the Cybex II, but did not first establish that the values could be reliably reproduced (Falke 1978, Fugl-Meyer et al 1979, Nickson 1987, Nistor et al 1982, Wong et al 1984).

Karnofel et al (1989) used a reciprocal test protocol to examine the reliability of ankle dorsiflexion/plantarflexion (DF/PF) and inversion/eversion (INV/EV) when tested by a single examiner (intra-tester) and two separate examiners (inter-tester) at angular velocities of 60°/s and 120°/s over three days. Table 1 details the method as it was reported. The study did not record the damp setting or the rest interval between the tests at the two angular velocities. The findings of this study demonstrated high reliability using the Pearson Product Moment Correlation Coefficient for mean peak torque for PF (r=0.91), INV (r=0.85) and DF (r between 0.87 and 0.89) both intra and inter-tester, and moderate reliability for inversion (r between 0.78 and 0.84) except intra-tester reliability at 120°/s which was high (r=0.89). Some points are important to note. The SEM and confidence intervals were not calculated, therefore the variance due to measurement error is unknown. Hence there is no indication of the torque score required to demonstrate a change in muscle performance (particularly with inversion which demonstrated low reliability). In addition, some details of the method have not been recorded which would make replication of these results difficult.

Leslie et al (1990) established the test-retest reliability of a test protocol for ankle inversion and eversion on the Cybex II. They examined the reliability of and differences in peak torque values in two groups of subjects, one whose end of range was limited at a known target point and the other who created their own end of range limit. Movements were examined at two angular velocities, 30°/s and 120°/s (further details of the methods are recorded in Table 1). Leslie et al (1990) do not state where the axis of movement was aligned, and the test position is not clearly described which makes replication of their results difficult. Interpretation of their reliability coefficients from the text and tables is unclear. The conclusion that the most reliable protocol for testing ankle inversion and eversion was with the inclusion of range of movement targets in a position of 20 degrees plantarflexion, is therefore open to question. However this investigation yields some useful information about the factors that might affect reliability at the ankle.

**Biodex**

The Biodex System is capable of measurement of several types of muscle action, isometric, isokinetic (concentric and eccentric) and passive, with a range of angular velocities between 10°/s and 450°/s (Malone 1988). Taylor et al (1991) found the Biodex to be an accurate and valid research tool, but advocated some caution with imputed torques and angular velocities to the limb being tested. Malone (1988), in his review of the commercially available dynamometers, states that trials with a known weight were conducted to validate the accuracy of the torque sensing hub. It was found to be 99 per cent accurate according to the author, however this statement was not referenced.

Montgomery et al (1989) established the reliability of isokinetic peak torque measurements of a reciprocal test protocol for knee flexion and extension on the Biodex System over a range of angular velocities (90, 150, 210, 270 and 330°/s). The method was recorded in detail (Table 1). ICC's ranged from R=0.75 for flexion at 270°/s to R=0.92 for extension at 90°/s. The reliability coefficients tended to decrease as the angular velocity increased, and in accordance the coefficient of variance (CV) increased as the angular velocity increased for both flexion and extension. Montgomery et al (1989) concluded that a change in the torque score of greater than 7 per cent would represent a change in muscle performance for all movements (except flexion at 330°/s (CV=11 per cent)) with their protocol. Physiotherapists using any type of isokinetic equipment need to eliminate as much measurement error as possible to be able to establish a test protocol that will be sensitive to small changes in muscle performance. Therefore it is important to consider the factors in this study which may have contributed to the error variance and hence the sensitivity of the test protocol to a change in muscle performance. These factors include: (i) the sequence of testing the angular velocities from slow to fast, (ii) the absence of a rest interval between the five maximal reciprocal muscle actions, and (iii) the choice of the single highest peak torque value as the criterion measure.

Feiring et al (1990) found high test-retest reliability for concentric peak torque for knee flexion and extension at a range of angular velocities on the Biodex System (60, 180, 240 and 300°/s). Their method can be found in Table 1. Some important omissions are noted that would render replication of this test protocol impossible despite the reports of high reliability.

**Shoulder**

No investigations were found in the literature on the reliability of isokinetic shoulder movements on any isokinetic dynamometer. A number of authors investigated various aspects of isokinetic torque measurements of shoulder movements but none

**Summary**

Review of the literature pertaining to the reliability of isokinetic torque measurements has revealed few investigations that establish reliable test protocols. Furthermore these studies are confined to a limited range of angular velocities, usually measure only peak torque for specific joint movements, and omit to report the standard error of measurement and confidence intervals for meaningful interpretation of the reliability coefficients. Therefore, clinicians and researchers who wish to utilise these few reliable test protocols must do so within the confines of the methodologies employed by each investigation at the angular velocities tested. As yet there is insufficient evidence to support extrapolation of data from a test protocol of one particular movement at one angular velocity and joint, to other angular velocities, movements and joints.

**Acknowledgements**

The author wishes to thank Professor Joan McMeeken, Professor Hugh Burry, Ms Jenny Keating and Mr Paul Lew for their constructive reviews of this paper.

**References**


From Page 133


