Cross-sectional and longitudinal uses of isoinertial, isometric, and isokinetic dynamometry

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Abstract

The purposes of this investigation were to assess whether maximal isoinertial (triceps pushdown [TP] and triceps extension [TE]), isometric and isokinetic (1.04, 2.08, 3.14, 4.16, and 5.20 rad·s⁻¹) forearm extension strength measures: 1) presented statistical generality when they were correlated prior to and following 4, 8, and 12 wk of resistance training; 2) were similarly affected by training; and 3) presented statistical generality when their changes as a consequence of training were intercorrelated. Fifteen men (11 experimental and 4 controls) without a history of resistance training participated in the study. Training involved four sets of 8-12 repetitions, each followed by 90-s recovery, at 70-75% one repetition maximum (1RM), three times a week, for 12 wk. Training incorporated the TP, close-grip bench press, and triceps kickback exercises. Prior to and after 4, 8, and 12 wk of training, the intercorrelations among the TP, isometric, and isokinetic indices almost always achieved statistical generality (i.e., r² > 0.5). It was concluded that the strength measures generally discriminated similarly between subjects. However, the sensitivity of the strength measures to the effects of training were dissimilar. While all strength indices increased with the training, the timing(isoinertial prior to isometric and isokinetic adaptations) and magnitude(TP>TE> isometric>isokinetic) of these adaptations varied greatly. None of the intercorrelations between changes in the strength indices achieved statistical generality. Furthermore, factor (F)-analyses on these changes indicated that in the initial and later stages of training, there were three and four discrete factors, respectively, accounting for strength development. These factors were thought to reflect differential effects of training on the structural,
neural (including learning), and mechanical mechanisms underpinning each strength index. Possible applications of this research design in better understanding strength development were also canvassed.

Strength has been defined as the maximum force exerted during a given pattern of movement or structural context (2), where structural contexts are delimited by the posture and segmental alignment during movement, mode of contraction and extent of loading during the movement, as well as the range and speed of movement (2,3). Clinicians and scientists often make inferences from data collected through dynamometry to strength performance in domestic, work, and recreational situations. These inferences may be broadly categorized as intra and intersubject (2). The intrasubject use of dynamometry is concerned with monitoring change in muscle function of a given individual (e.g., change due to training or rehabilitation regimens), while intersubject use is concerned with discriminating between individuals (e.g., athletic talent identification).

A critical issue to be considered when using dynamometry to discriminate between individuals is whether some or all forms of dynamometry similarly rank (strongest-weakest) a group of individuals (2,3,9). The evidence that various forms of dynamometry discriminate between individuals is equivocal (2,3,9). For example, Hortobagyi et al. (9) found that in excess of half of the variance between isokinetic, hydraulic, and isoinertial bench press tasks was shared (r ≈ 0.8), while Baker et al. (3) reported that only one-third of the variance was shared between the one-repetition maximum (1RM) bench press and a maximal isometric chest task (r = 0.6). Additional research is required to determine why there are these inconsistencies within the literature.

A fundamental intrasubject issue is whether the effects of training interventions are detected by various forms of dynamometry. This issue can be addressed at several levels. The first level disregards sensitivity, and asks whether all forms of dynamometry detect changes in strength arising from an intervention. Again the data are equivocal. Twelve weeks of squat and bench press training at 6-RM loads has been shown to significantly increase 1RM squat and isometric leg strength values (2). While in contrast, 8-wk isokinetic training of one leg produced significant increments in isokinetic, but not 1RM, strength; and isoinertial training of the contralateral limb increased 1RM, but not isokinetic strength (18). More research is required to delimit when various forms of dynamometry are sensitive to the effects of particular regimens for given individuals. Second, even if various strength indices detect the effects of intervention, can it be assumed that they are similarly sensitive? The fact that several authors have reported that resistance training increases strength in one modality, but not another, indicates that sensitivity varies between strength measures (7,22). Third, are the various forms of dynamometry that are sensitive to interventions being modified by similar mechanisms? The poor intercorrelation between change in isometric chest and 1RM bench press strength (r = 0.1) reported by Baker et al. (21) suggested not. Clearly, it is essential to determine the number, sequence, and nature of mechanistic events underpinning changes in particular strength indices if we are to: 1) make inferences from these strength indices to other structural contexts; and 2) better understand the effects of particular interventions.

The purpose of this investigation was to systematically address some of the intra and intersubject uses of isoinertial, isometric, and isokinetic dynamometry prior to and after 4, 8, and 12 wk free weight training of the forearm extensors.
METHODS

Subjects

Fifteen male university students with a history of recreational physical activity, but not systematic resistance exercise, participated in this investigation. Eleven subjects volunteered to complete 12 wk of resistance activity (age: 19.5 ± 1.0 yr; mass: 80.3 ± 11.6 kg; height: 181.1 ± 6.3 cm), while the remaining subjects acted as controls (age: 24.5 ± 4.2 yr; mass: 72.8 ± 7.2 kg; height: 172.6 ± 2.9 cm). Subjects provided informed written consent for the investigation, which conformed to the Australian National Health and Medical Research Council's guidelines for research with human subjects, and was approved by the Medical Research Ethics Committee of The University of Queensland. Training and testing were performed at the Human Performance Laboratory at the Department of Human Movement Studies of The University of Queensland.

Procedures

For the week prior to the 12-wk investigation, subjects did not complete strenous or unaccustomed physical activity. On the first days of this week subjects were familiarized with the strength testing procedures (i.e., completed all tests in the manner and order described below). On day 7 actual measurements were made (W0). Additional measurements were made after 4 (W4), 8 (W8), and 12 (W12) wk of the training period.

Measurement of strength. Strength was measured in isoinertial, isometric, and isokinetic contexts. Isokinetic testing preceded isometric assessment, which in turn preceded isoinertial assessment. There were, respectively, 2- and 15-min recovery periods between the conclusion of isokinetic and commencement of isometric assessment, and the conclusion of isometric and the commencement of isoinertial assessment.

Peak isokinetic forearm extension torque was determined at 1.04, 2.08, 3.14, 4.16, and 5.20 rad·s⁻¹ during cycles of maximal voluntary extension and flexion of the nondominant forearm on a Cybex 340 dynamometer (Cybex Corporation, Lumex, Bay Shore, U.S.A.). To minimize any possible order effect, the order in which contractile speeds were tested was randomized for each subject at W0, and retained for W4, W8, and W12. Continuous trials of three and five maximal contractions per trial were completed at 1.04, 2.08, 3.14 rad·s⁻¹, and 4.16 and 5.20 rad·s⁻¹, respectively. Peak torque (Nm) was the highest nonartifact, gravity-corrected value obtained at each test velocity [4]. Prior to testing, the subjects completed warm-up movements at contractile speeds between 2.08 and 4.16 rad·s⁻¹. There was a 60-s recovery period between the warm-up and first series of contractions and each subsequent series of repetitions. Isometric strength (0.00 rad·s⁻¹) was the most forceful of three contractions performed on the Cybex 340 dynamometer at an angle of 0.52 rad from full extension.

During isokinetic and isometric testing the dynamometer was adjusted so that it stood at its minimum height. The subject lay in a supine position on the upper body exercise table (UBXT) adjacent to the dynamometer, and was positioned so that the center of rotation of the elbow joint corresponded with the center of rotation of the dynamometer. To minimize arm and shoulder girdle involvement the arm was strapped to a supporting pad. The arm was abducted so that the angle between the arm and trunk was 0.78 rad. The distance between the medial epicondyle of the humerus and anterior superior iliac spine was the same at all measurement occasions. The wrist joint was held in the supinated
position by a molded brace. The trunk of the subject was anchored to the UBXT by a waist strap. The knees were bent at 1.56 rad over the end of the UBXT. Feet were placed on a footrest. The lever arm (L-shaped adapter and fixed handgrip) of the dynamometer was held by the hand in a supinated position. The endpoints of the range of movement of the forearm corresponded with full extension and full flexion. The positioning of the handpiece and the length of the lever arm was constant at all times for each individual subject. The application of each of these parameters ensured that subject positioning was identical on all occasions.

The 1RM for the TP and lying TE was used to assess changes in the isoinertial strength of the elbow extensors. In this assessment the TP task preceded the TE. The warm-up for these tasks involved repeat efforts approximating 25% of body weight. At W0 the initial test load approximated 30% of body weight, with each successful repetition seeing an additional 2.5-5.0 kg being added. At subsequent measurement occasions (W4, W8, and W12) the initial test load was 2.5 kg less than the 1RM of the previous assessment occasion. There was a 5-min recovery period between efforts and exercises. The speed of movement during TP and TE efforts was not controlled in any way. As has been reported previously, this procedure saw 1RM being obtained usually within four trials (2).

During the TP the subject faced the pulley system in an upright position. The arms were held in a position parallel with the trunk, while the forearms pulled the bar through a cycle from full forearm flexion to extension (during the downward stroke the weights were raised). The arm as well as the forearm was involved during the upward stroke, while a bench horizontally supported the head, trunk, and thighs of the subject in a supine position during the TE. The legs were flexed at right angles over the end of the bench, with the feet flat and comfortably positioned upon the floor. The arms were flexed at right angles to the ground and the dumbbell grasped in the neutral (hammer) position, while the forearms moved the dumbbell through cycles of full forearm flexion and extension. The supervisor ensured that the arms were not involved during these cycles.

Training. Subjects completed three bodybuilding-type resistance sessions each week (Monday, Wednesday, Friday) for 12 wk. Strength assessments were conducted on the Wednesday of W4, W8, and W12, and represented the training session for that day. All sessions were supervised.

Sessions were preceded and followed by 10-15 min of flexibility and calisthenic exercises involving all body regions. In addition to the three resistance exercises (TP, close-grip bench press, and triceps kickback) used to develop forearm extension strength, subjects also completed the biceps curl exercise. With the exception of the TP (i.e., a pulley arrangement), exercises were performed with free weights. Subjects completed the four sets of each exercise prior to undertaking the next exercise. The recovery period between sets and exercises was limited to 90 s. Each set involved between 8 and 12 repetitions with loads of 70-75% of 1RM. When 12 repetitions had been completed for each set of a given exercise in two successive sessions, 1RM was reassessed and a new weight for that exercise prescribed.

Data Analysis

To determine if the isometric, isoinertial, and isokinetic indices were measuring a common strength property, two sets of F-analyses were conducted on these measures at W0, W4, W8, and W12. The first set of F-analyses involved data from the experimental and control subjects, while the remaining set involved only experimental subjects. The principal components method, default option of the Statview 512+ program, and
orthotran-varimax procedure were used respectively in F extraction, determining the number of factors, and in F transformation. In all F-analyses the assumptions of the matrix sampling adequacy and sphericity were tested and met. The decision of whether orthogonal or oblique solutions were to be used was based upon the clustering of the data in the orthogonally rotated context. In addition, intercorrelations (Pearson Product Moment correlations) between the various strength indices were reported, despite the data not being normally distributed. However, this approach was acceptable as shared variance of, and not the significance of the relationship between, the dependent variables being sought (Howard, personal communication). Statistical generality and specificity, respectively, were thought to have been achieved when the shared variance was greater than and less than 50%, respectively.

Friedman repeated measures analyses of variance (ANOVA) by ranks were used to determine whether 4-, 8-, and 12-wk training affected any of the dependent variables \(P < 0.05\). This approach was adopted as the skewness and kurtosis of the raw data and its logarithmic transformation departed from zero. The Wilcoxon matched-pairs signed-ranks test was used where post-hoc analysis was required. The coefficient variation (CV) and ES transformations were used to compare changes in the various strength indices as a consequence of training. The mean and standard deviations used in calculating the CV and ES were based upon differences in strength values between W0 and W12. To ascertain whether the dependent variables were influenced by similar effects following 4, 8, and 12 wk of resistance training, the value changes in various strength indices for the experimental group were intercorrelated (Pearson product moment correlation-see above), and entered into F-analyses (see above).

RESULTS

Were the Strength Indices Able to Discriminate Between Subjects?

The F-analyses involving experimental and control subjects conducted at W0, W4, W8, and W12 were resolved into two orthogonal factors, which were highly correlated (correlations between F1-F2: W0 = 0.91; W4 = 0.84; W8 = 0.97; W12 = 0.81). F1 accounted for approximately 95% of the common variance at each measurement occasion. Furthermore, on all occasions the isoinertial, isometric, and isokinetic indices were strongly associated with F1. Consequently, it was not surprising that the Pearson product moment intercorrelations between the dependent variables at W0, W4, W8, and W12 attained statistical generality (i.e., \(r^2 > 0.50\))(Tables 1 and 2). The only apparent anomalies to this rule were the intercorrelations between TE and isokinetic indices between W4 and W12 (Table 2). Taken together, these data indicated that all strength indices discriminated between individuals' strength similarly. However, this was not always the case when the same analyses were conducted only upon the W4, W8, and W12 scores of the experimental subjects. The best-resolution F-analyses were oblique (correlations between F1-F2: W4 = 0.65, W8 = 0.54, W12 = 0.70) and with some strength indices more strongly aligned with F2 than F1 (W4 = TE, W8 = TE, W12 = TP and TE). This indicated that there was a shift in F influence over the training period (W0 F1’s relative contribution to variance was 0.95; W12 relative contribution to variance: direct F1 = 0.44, F2 = 0.29, shared = 0.23). It can also been seen that by W12 the shared variance between the isoinertial and other measures was often less than 50%(Table 3).

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Did the Strength Indices Detect a Training Effect?

Training saw TP strength increase significantly and progressively over the three training epochs (i.e., W12>W8>W4>W0) (Table 4); while TE strength increased, plateaued, and then continued to increase over the first, second, and third training epochs, respectively (i.e., W12=W8=W4>W0) (Table 4). However, significant increments in isometric and isokinetic strength were not evident prior to the completion of the second training epoch (i.e., W8). Furthermore, with the single exception of 3.14 rad·s⁻¹, isometric and isokinetic strength plateaued between W8 and W12 (i.e., W12=W8≈W4≈W0). Torques generated at 3.14 rad·s⁻¹ fell between W8 and W12. These experimental data indicated that the temporal sensitivity (i.e., time taken for a significant increment in strength to be detected) differed between strength indices (Table 4). Furthermore, there was a marked variation between strength indices in relation to changes in magnitude produced by training (Table 5). Had all strength indices been similarly sensitive to the effects of training, then CV and ES would have been of a similar magnitude. The ES transformations between W0 and W12 indicated a hierarchy of sensitivity to training (isoinertial > isometric> isokinetic) (Table 5).

Table 5

| Image Tools |

Table 4

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The ES data for TP and isokinetic data (except 2.08 rad·s⁻¹) supported the ANOVA data that strength was not markedly different at any of the measurement occasions for the control group (Table 4). However, changes in isometric strength (ES = 0.6), isokinetic strength at the 2.08 rad·s⁻¹ (ES = 0.5), and TE (ES = 1.8) were moderate to very large (Table 4). The fact that significant ANOVA outcomes were only found for TE was thought to be due to the low statistical power of the control condition.

Strength Development

None of the intercorrelations between changes in the strength indices between W0 and W12 were strongly positive (r ranges: -0.74-0.53) (Table 6). The related F-analysis identified four factors(correlations between F1-F2 = -0.09, F1-F3 = -0.11, F1-F4 = -0.12, F2-F3 = -0.02, F2-F4 = 0.11, F3-F4 = 0.06) (Table 7). The proportion of the variance directly accounted for by factors 1, 2, 3, and 4 was 0.33, 0.26, 0.23, and 0.23, respectively. Critically, the joint proportionate contribution of the four factors was negligible, suggesting that the mechanisms for adaptation underpinning each F were acting independently of one another. While we are not in a situation to identify the mechanisms underpinning each of the factors, these data do suggest that there is a complex interaction underpinning improvements in the considered strength indices (Table 7). The F analyses associated with changes in strength values for each training epoch (W0-W4, W4-W8, and W8-W12) were similar in many ways to that just reported for W0-W12 (Table 7). However, dependent variables that were strongly correlated with a common F over one training epoch were not necessarily linked to a common factor over another training epoch. Furthermore, the F-analyses for W0-W4 and W4-W8 only identified three factors, whereas changes from W8-W12 and W0-W12 had four factors. This is consistent with the
suggestion that there is a sequence of mechanistic adaptations in response to resistance training.

**DISCUSSION**

Prior to training the isoinertial, isometric, and isokinetic indices ranked subjects similarly on forearm extensor strength. However, with training, statistical generality was not always evident between isoinertial measures, particularly TE, and isometric and isokinetic measures. The results clearly indicated that neither sensitivity of, nor the mechanisms underpinning improvements in, the various strength measures was similar.

Throughout this paper regular reference is made to statistical generality. Care should be exercised when using the concept of statistical generality to examine relationships between indices. A correlation coefficient of 0.71 not only means that 50% of the variance is shared, but also that half of the variance is not shared. Consequently, consideration was given to using a more stringent correlation coefficient; however, its selection would have been arbitrary. Thus, we urge readers to consider both the variance that is shared and that which is not shared when examining intercorrelations.

Logistical considerations meant that the order in which isokinetic, isometric, and isoinertial testing was conducted could not be randomized. Conceivably, this ordering of assessment may have introduced a systematic bias to these data. However, this was thought unlikely. While a generalized, acute fatigue may cause such a bias, the recovery periods used have been reported to be sufficient to minimize such fatigue. If systematic error accounted for our data we should have seen similar F-analyses at each measurement occasion for all subjects. This was not the case for the experimental subjects (i.e., 1 F at W0 and two factors at W4, W8, and W12). Finally, this fatigue would have been most evident in the final measurement (i.e., TE), yet TE in the control group increased at W4 and W12.

**Intersubject Discrimination**

The substantial common variance (i.e., $r^2 = 0.53-0.92$) reported among the isometric, isokinetic, and isoinertial strength indices at W0 suggested that all indices could be used to discriminate between the strengths of active, but not systematically trained, young males (Table 1). Statistical generality was usually maintained even when the sample was altered to contain individuals who had no training, and others with up to 3 months of systematic resistance exercise (Table 2). Interestingly, statistical generality was not always evident between the isoinertial (TP and TE) and other strength measures for the experimental subjects following 12 wk of training (Table 3). Why this was the case was not immediately apparent. It could be argued that the probability of statistical between indices decreases with training. The existence of isometric-isokinetic and isoinertial factors at W12 tended to support this contention. Furthermore, the shared variance between the isometric and isoinertial strength indices, for both the upper and lower body, has previously been shown to be only one-third in males with a history of 6 months’ resistance training. Equally, however, the poorer correlations between TE and other indices may have been related to learning associated
with the TE across the training period. Evidence for such a learning effect was seen in the control group, which increased TE strength over the 12 wk of the study (Table 4). The highly controlled, single-joint isometric and isokinetic tasks may be learned faster than the complex and less controlled TP and TE. However, this suggestion does not explain why there was a learning effect for TE, but not TP. Clearly, these issues require further investigation. At a practical level it also suggests that some strength indices need more familiarization than others. Our data would suggest that this may be the case for isokinetic loading at 2.08 rad·s\(^{-1}\), TE, and isometric tasks.

**Intrasubject Discrimination**

In this and other investigations, strength has been measured prior to and following training with modalities different from or in addition to those used in training (e.g., 10, 20, 22). However, do data from modalities differing from the training modality accurately reflect the effects of training? While we found that 12 wk of isoinertial training significantly increased isoinertial, isometric, and isokinetic strength, the sensitivity of the various indices varied greatly.

The temporal sensitivity of isometric and isokinetic indices were significantly less than isoinertial measures (Table 4). This suggests that isoinertial indices should be used when endeavoring to accurately plot temporal changes in strength as a consequence of weight training. Furthermore, within the domain of isoinertial measures, one test should closely mimic at least one of the strengthening exercises, as not all isoinertial indices accurately reflect the temporal changes in strength (see TE data in (Table 4). The ES data of Table 5 clearly indicated that training (and learning) had a greater effect on the magnitude of isoinertial strength development (TP and TE) than isometric and isokinetic strength indices. The much larger CV for isometric, and particularly isokinetic, indices also suggested that the efficacy of training was more variable in these modalities than the isoinertial domain. This reduced effect on the isokinetic and isometric modalities was consistent with our ANOVA results presented in Table 4.

**Strength Development**

Our understanding of the mechanisms underpinning strength development is incomplete (e.g., 14). Strength adaptations following training regimens are the outcome of a complex interplay between program (i.e., modality, intensity, duration, frequency, and inter-set recoveries), phenotypic (i.e., physical activity history and current resistance and other training practices), and genotypic inputs on structural, neural, and mechanical factors (3). These factors are in turn the product of many elements, some of which can be modified by training. Structural factors include posture and segmental alignment during movement, as well as the modality and speed of contraction. Neural factors include motor unit recruitment within a given muscle; the interplay among agonists, fixators, synergists, and antagonists; the role of the gamma-motor loop; and contralateral and bilateral interactions; while mechanical factors include the cross-sectional area of muscle and muscle fibers, the myosin heavy and light chain isofor m profiles of fibers, the specific tension of fibers, and the role of the stretch-shorten cycle. The results of the F-analysis indicate that in the initial two training epochs (W0-W4 and W4-W8) that strength adaptations were underpinned by changes to at least three elements; while in the final epoch (W8-W12) there were changes to at least four elements (Table 7). Our data did not allow us to match mechanisms with various factors, though they do illustrate the
oversimplification that saw strength improvements previously attributed to neural adaptations followed by muscle hypertrophy. 

The approach of testing multiple strength indices and then conducting F-analyses on their flux over various training epochs may facilitate the description of the number, sequence, and interaction of factors implicated in the development of strength in response to a particular training regimen for a particular group. Clearly, there is a need to go beyond this descriptive work to match particular mechanisms or combinations of mechanisms to particular factors through the use of rigorous, longitudinal investigations. If such matching can be completed, then it is conceivable that models of strength development, which take into account the interplay among structural, neural, and mechanical factors, can be developed that are sensitive to the influences of genotypic and phenotypic factors.

Increments in the isoinertial TE were neither well-correlated with, nor as large as, the changes in the isoinertial TP. Only in the W4-W8 training epoch were changes in the TP and TE associated with a common F. These data suggested that different mechanisms transferred the effects of isoinertial training to isoinertial movements similar (i.e., the TP) and dis-similar (i.e., the TE) to those of training. The fact that TE increased with training indicated that there were common components underpinning increments in TP and TE strength (perhaps mechanical and neural factors). Equally, however, the poor intercorrelations between the changes in the two variables indicated that large components of adaptation were different (i.e., structural and perhaps neural factors). Interestingly, Rasch and Morehouse also reported that training improvements were not as well transferred to non-trained movements involving the same agonists.

Isoinertial training produced a greater training effect on isometric strength than the dynamic isokinetic indices. This clearly illustrates that the structural, neural, and mechanistic adaptations associated with dynamic isoinertial training had little effect on the performance of the dynamic isokinetic tasks. This conclusion was supported by the poor intercorrelations between change in isokinetic and TP and F-analyses across the various training epochs. Clearly, there were positive adaptations to a small component of neural and/or mechanistic adaptations common to improvements in TP, isometric, and isokinetic performance following training. However, the temporal lag and much smaller effect of training on isometric and isokinetic indices illustrate the declining potency of isoinertial training on these parameters. These data highlight the need for care when selecting dependent variables to assess the effects of training (see Abernethy et al. for a more detailed discussion).

SUMMARY

The isoinertial, isometric, and isokinetic indices used in this investigation produced similar rankings of elbow extensor strength in a group of 15 male university students who did not have a history of resistance training. That is, there appeared to be little difference between strength indices when trying to discriminate between individuals (i.e., in an intersubject context). However, the selection of the strength indices was critical when monitoring the effects of 12-wk isoinertial training (i.e., in an intrasubject context), while 12-wk isoinertial training increased isoinertial, isometric, and isokinetic strength. The interplay between structural characteristics of the strength indices and changes to neural and/or mechanistic properties with training (and learning) meant that the timing and magnitude of isoinertial, isometric, and isokinetic strength varied greatly. The use of F-analyses to monitor changes in various strength parameters with training, and subsequent research to link mechanisms to the resultant factors, may make it possible to
develop comprehensive models for strength development that take into account the characteristics of the exercise regimen and the pheno and genotypic characteristics of the participant.

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RESTATEMENT TRAINING; DISCRIMINATION; GENERALITY

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