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Generality versus specificity: a comparison of dynamic and isometric measures of strength and speed-strength

Daniel Baker[1], **Greg Wilson**[1], **Bob Carlyon**[2]

[1] Centre for Human Movement Science and Sports Management, The University of New England-Northern Rivers, P.O. Box 157, Lismore, 2480 NSW, Australia
[2] Department of Human Movement Studies, The University of Queensland, St. Lucia, QLD, Australia

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Abstract. Considerable debate exists as to whether the qualities of muscle function exist as general or specific physiological capacities. If there is a generality of muscle function then strong relationships would exist between various measures of function for the same muscle(s), independent of the test contraction, mode or velocity. The purpose of this study was to examine the relationship between isometric and dynamic measures of muscle function to determine the existence of generality or specificity. A group of 22 men, experienced in weight training, were tested for lower and upper body dynamic and isometric measures of strength and speed-strength. The changes in these measures consequent to a resistance training programme were also investigated. The results of this study indicated that whilst isometric and dynamic measures of strength did significantly correlate ($r=0.57$–0.61), the relationship was below that required to denote statistical generality. More important, the changes in isometric and dynamic strength consequent to a dynamic heavy resistance training programme were unrelated ($r=0.12$–0.15). Thus the mechanisms that contribute to enhanced dynamic strength appearred unrelated to the mechanisms that contribute to enhanced isometric strength. Measures of dynamic and isometric speed-strength were unrelated, as were the changes in these measures resulting from training. The results of this study demonstrated that a generality of muscle function did not exist and that modality specific results were observed. Consequently this study calls into question the validity of isometric tests to monitor dynamically induced training adaptations.

Key words: Muscle testing modalities – Strength training – Performance assessment – Rate of force development

Introduction

Muscle function can be trained and measured by a variety of methods characterized as the iso-inertial, isokinetic, semi-isokinetic and isometric testing modalities. Further, the contraction mode (concentric, eccentric or isometric) and velocity may vary considerably in training and testing (Knuttgen and Kraemer 1987; Hortobagyi et al. 1989). The confusion arising from the various means by which function can be defined or measured has led to many discrepancies in the literature, especially when comparisons between various training and testing modes have been made (Knuttgen and Kraemer 1987).

Traditionally researchers have utilized isometric testing of muscle function and have extrapolated isometric strength as being equivalent to dynamic strength (Rasch 1957). It was thought that by measuring isometric strength qualities, an insight into the often more desired dynamic strength qualities were gained. Consequently, the practice of laboratory testing of muscle strength via isometric means (strain gauges, load cells and force platforms), to determine the dynamic strength capabilities of the musculature, has appearred widespread (Costill et al. 1968; Sale and Norman 1982; Young and Bilby 1993). Despite the evidence that strength training has had specific effects (Hakkinen et al. 1985a,b) it would appear that a school of thought promotes the concept of a "generality" of strength (Hortobagyi et al. 1989).

If muscle strength exists in general, rather than in specific terms, then individuals would rank similarly despite different testing apparatus, contraction velocities and modes of contraction. Consequently, virtually any test performed upon the same muscles would appear valid and could discriminate between "strong" and "less strong" individuals. The crucial statistical test to validate this concept of generality would be a correlation of $r=0.71$ or greater (Clarke and Clarke 1970), as this would suggest a minimum of 50% of common variance. Research has provided support for the existence of a general strength component, based upon

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Correspondence to: D. Baker

correlations of $r > 0.71$, when comparing different methods of strength assessment (Otis 1976; Knapik and Ramos 1980; LaChance et al. 1987; Hortobagyi et al. 1989). However, other researchers have reported less generality, and greater specificity of strength, when comparing isometric to the dynamic measures of isokinetic and isoinertial tests (Olson et al. 1972; Osternig et al. 1977; Hortibagyi et al. 1987; Sale et al. 1992; Young and Bilby 1993). Consequently, differences exist in the literature concerning the relationship between "strength" measured by various means and specifically the relationship between isometric and dynamic measures of strength. In addition, a paucity of data exists relating dynamic measures of speed-strength, such as vertical jumps and isometric measures of "speed-strength", such as the rate of force development. This paucity of data is surprising in the light of the widespread use of the isometric rate of force development test in the literature (Sale and Norman 1982; Hakkinen et al. 1985a, b; Young and Bilby 1993).

The purpose of this paper is to determine the relationship between dynamic and isometric measures of strength and speed-strength and the relationship of the muscle function changes in these two forms of measurement consequent to a heavy resistance weight training programme. The extent of the relationship between the various measures of strength and speed-strength and the resultant changes consequent to strength training should provide data pertinent to the validity of strength and speed-strength testing and to the concept of generality versus specificity.

Methods

Subjects. A group of 22 men, who possessed a minimum of 6 months' previous weight training experience, volunteered and gave informed consent to participate in this study. Their mean age, height and body mass were 20.0 (SD 2.6) years, 179.6 (SD 5.9) cm and 75.0 (SD 8.4) kg, respectively. Experienced subjects were chosen for this study as they were accustomed to training and testing and thus the changes induced by training would be less likely to be influenced by a learning effect, in comparison to novice subjects (Rutherford and Jones 1986).

Training. All the subjects performed strength training programmes of equal amounts and intensity 3 days$\cdot$week^{-1} for 12 weeks. The training involved the performance of 720–732 repetitions, excluding lighter warm-up repetitions, in the squat and bench press lifts and 360–366 repetitions in the clean pull over the 12-week period. The mean relative load (total repetitions/total sets) for these exercises was 6 RM (repetition maximum). To simulate the actual training of strength athletes, additional exercises were also performed for the upper body such as arm curls, tricep pushdowns, chin-ups and rowing. The amount and intensity of these additional upper body exercises were three sets of 6–10 RM and were similar for all subjects.

The subjects were tested on a number of dynamic and isometric strength and speed-strength measures prior to and after the training period. Prior to each testing session the subjects were thoroughly warmed up and familiarised with the test items.

Dynamic strength testing. Dynamic strength was determined using standard free weight barbell exercises. Dynamic lower body maximal strength was assessed via the 1 RM squat using the methods described by Stone et al. (1981). Dynamic upper body strength was assessed via the 1 RM bench press using the methods described by Wilson et al. (1992). In both instances, the subjects performed their usual personal warm-up which included stretching and lifting light loads in the exercise to be assessed. After warming up, the subjects performed single repetitions only, with progressive increments in the barbell load of initially 10–20 kg decreasing to the minimal load increment of 2.5 kg as the subjects neared their perceived 1-RM load. The dynamic 1-RM load was usually determined within 5–8 attempts. The rest period between attempts was at the subjects' discretion and was typically in the range of 3–5 min.

Isometric strength testing. Isometric strength was assessed for the lower and upper body utilizing a 0–1000 N Medelec load cell system. The load cell was calibrated by recording the output from a series of known loads of 0–100 kg. The load cell was positioned in series with the system so that the direct line of force was recorded. The force signal was recorded on an IBM-AT compatible computer and analysed using the Wasp system software (Quantec Systems, University of Queensland, St. Lucia). For the lower body, isometric strength was assessed by a unilateral isometric leg extension (leg test) with knee and hip angles of 90° and 110°, respectively, using the procedures of Hakkinen and Komi (1983). Upper body isometric strength was assessed via a unilateral isometric bench press (chest test), modified from Schmidtbleicher and Bhuerle (1987), so that the hand was positioned at the chest, as per the initial position of the concentric phase of the bench press. Two trials were performed for each of the isometric tests with the trial recording the highest force output used for further analysis.

Vertical jump. Vertical jump (VJ) height was assessed via the jump and reach procedure (Sargent 1924) to monitor dynamic speed-strength adaptations. After a number of warm-up jumps, the best effort trial from two maximal countermovement jumps with arm swing was recorded to the nearest 0.5 cm and recorded as work done (mass × gravity × height).

Isometric rate of force development. The isometric rate of force development test was utilized as a measure of isometric speed-strength and quantified as the time taken to reach 400 N of force in the leg test (F-T 400 N), using the procedures outlined by Hakkinen et al. (1985a).

Isometric impulse. The impulse of the isometric force signal was determined to monitor adaptations in isometric speed-strength and to establish the relationship to dynamic measures (VJ). A time frame of 350 ms, commencing at the first visible increase in the force signal, was chosen as this has been found approximately to equate to the concentric foot contact time during a VJ (Hakkinen and Komi 1985). Consequently, it was hypothesized that if VJ improved and a generality of muscle strength/power existed, then the impulse from the isometric leg extension force signal over a similar time frame should also improve.

Statistical analysis. Prior to the commencement, and at the completion of the 12-week training programme, the relationship between the various measures of strength and speed-strength were determined using a Pearsons product moment correlation. The differences between the measures of muscle function, pre to post-resistance training programme, were determined for significance by a paired Student's *t*-test. The relationship between the changes in strength and speed-strength in the measured variables resulting from the training programme were also investigated to determine if the mechanisms underlying the changes in muscle function were common among the tests. A correlation of $r = 0.71$ or greater, indicating 50% or more of common variance, was chosen to indicate a generality of the strength relationship (Clarke and Clarke 1970). Statistical significance was set at the 0.05 α level for all measured tests.

Results

A detailed description of the changes in the various measures of strength and speed-strength is contained in Table 1. The relationship between the various measures of strength and speed-strength and the extent of the relationship between changes in one measure of function compared to another are contained in Table 2. Prior to and after the commencement of training the dynamic squat strength significantly correlated with the isometric leg extension strength ($r=0.57$), but the extent of the relationship was below that which is required to denote statistical generality. After the completion of training, the 1-RM squat and the isometric leg extension strength had both increased significantly. The 27.2% improvement in the 1-RM squat and the 8.7% improvement in isometric leg strength were unrelated ($r=0.16$).

Prior to training the dynamic and isometric bench press strength were also significantly related ($r=0.57$), however the strength of the relationship was below that needed to denote generality. After the completion of training, the dynamic and isometric bench press strength had increased significantly above pretest measures. The relationship between the two posttraining measures of strength was similar to that at the pretest period ($r=0.61$). The 13.1% change in dynamic bench press strength and the 19.4% change in isometric bench press strength were unrelated ($r=0.12$).

Table 1. Results for the various measures of strength and speed-strength at the pre- and post-testing occasions

	Pre		Post	
Dynamic tests	mean	SD	mean	SD
1 RM Squat (kg)	112.7	24.9	141.0	23.5*
1 RM Bench press (kg)	82.1	11.7	92.6	11.5*
Vertical jump (cm)	49.7	6.9	53.3	5.9*
Vertical jump work (J)	365.6	66.9	404.0	63.9*
Isometric tests				
Leg test (N)	559.7	105.0	598.5	79.8*
Chest test (N)	323.7	77.2	377.0	59.5*
Isometric impulse (Ns)	1215.3	181.8	1180.2	198.1
F-T 400 N (ms)	208.3	87.9	196.3	65.4

RM, Repetition maximum

*Significantly different ($P<0.05$) from the pre to post-testing occasion

Table 2. Correlations for the various measures of muscle function at the pre and post-testing occasions and the correlation between the percentage change in this data as a consequence of resistance training

Strength tests	Correlation coefficients		
Dynamic vs Isometric	Pretest	Posttest	% Change
SQ vs LG	0.575*	0.57*	0.156
BP vs CH	0.568*	0.614*	0.12
VJ vs F-T 400 N	0.098	0.127	0.072
VJ vs IM	0.39*	−0.225*	−0.034
VJ W vs F-T 400	−0.344	−0.328	−0.247
VJ W vs IM	0.518*	0.366*	0.14

*Statistically significant ($P<0.05$)

SQ, Squat; LG, isometric leg test; BP, bench press; CH, isometric chest test VJ, vertical jump; F-T 400 N, time to reach 400 N of force in the isometric leg test; IM, impulse of the first 350 ms of the isometric leg test force signal; *W*, work

The relationship between VJ performance, quantified either as height jumped or work done, and the F-T 400 N was nonsignificant at the pre and post-testing periods. The impulse of the isometric knee extension and the VJ height were significantly related prior to training but unrelated at the post-testing period. The VJ work and isometric impulse were correlated at both test occasions. However, both measures of isometric speed-strength were statistically unchanged as a result of training, whereas the VJ height and work both increased significantly as a result of training. The relationship between the changes in both measures of VJ performance and the F-T 400 N, consequent to strength training, were also nonsignificant. The statistically significant changes of 8.3% and 11.5% in VJ height and work respectively, were also not related to the unaltered performance in the isometric impulse.

Discussion

The low relationship between the dynamic and isometric tests of strength and speed-strength indicate that muscle function measures are specific to the test modality, rather than general qualities. The correlations between the 1 RM squat and the isometric leg test at the post-testing period would suggest that only 32% of the variance of the measures is common. Further the changes in strength performance in the 1-RM squat and the isometric leg test were unrelated, indicating that different mechanisms may underlie the changed performance in these two measures of strength. This finding supports the work of Thorstensson et al. (1976) and Sale et al. (1992) who have reported no change in isometric unilateral leg extension strength despite large improvements in dynamic weightlifting strength.

The results were virtually the same for the upper body measures of strength. The 1-RM bench press had only a common variance of 37% with the isometric chest test, despite the fact that they are supposed to be measuring the same quality. Also the training induced changes in 1-RM bench press and isometric chest test were unrelated, again indicating that the mechanisms that underlie changes in performance in a dynamic test of strength are not the same as those that underlie changes in an isometric test of strength.

The measures of speed-strength, the dynamic VJ and the isometric F-T 400 N and impulse were, in the main, unrelated. This finding is supported by recent research performed by Young and Bilby (1993) who have reported that VJ height and maximal isometric rate of force development were unrelated ($r=-0.07$). Further, the training induced significant increase in VJ height, indicating an increased ability to generate force rapidly in dynamic contractions, was unrelated to the unchanged performance in the isometric tests. This would seem to indicate that training induced speed-strength adaptations are also mode specific. Consequently, isometric tests may not be valid for the monitoring of neuromuscular adaptations supposed to be induced through dynamic training. Possible explanations in support of the specificity over generality concept, may lie in the structural, neural and mechanical differences between dynamic and isometric testing of strength.

Structural considerations

The fact that the isometric leg test and the 1-RM squat are structurally different may account for a portion of the observable differences in the relationship between the measures. Other researchers have found similar relationships between 1-RM squat and dynamic leg extension tests ($r=0.6$; Hortobagyi et al. 1987) which indicates the structure of the test, and not merely the mode (isometric versus dynamic), affects the extent of the relationship between the measures of strength. Consequently, the strength of the leg extensors measured seated, and with stable angles about the various other joints, does not account for 40% of the variance of strength measured during a squatting movement. This would indicate that the strength of the musculature may be specific to a movement pattern, regardless of whether the tests are isometric or dynamic.

Whilst the structural differences between a seated isometric leg extension test and a dynamic squat would appear to account for the lack of a general relationship between the two measures, this could not be argued in the case of the dynamic bench press and the isometric chest test. The chest test was chosen to resemble, as closely as possible, the starting position for a dynamic bench press. Hence it was expected that the dynamic bench press strength would correlate very strongly with the isometric chest test results. However, at the post-testing period the extent of the relationship suggested that only 37% of the variance was common. Consequently, even in a structurally similar test the relationship between dynamic and isometric measures of strength indicates that a specificity, not generality, of strength exists.

Neural considerations

The different structural aspects of the two exercises could also modify the neural recruitment patterns and hence the force output of the musculature may be affected accordingly. As a muscle moves through a range of motion, it has been shown that there may be preferential recruitment of certain motor units at certain positions or angles (Ter Haar Romeny et al. 1982; Caldwell et al. 1993). However, the 90° angle for the leg test only equates to one position of the dynamic squat. Further, the squat is most often performed with the toes pointing slightly outwards, whilst the leg test is performed with the toes pointing straight ahead, a difference in position affecting the line of pull that has been shown in other muscle groups to alter the neural recruitment patterns (Ter Haar Romeny et al. 1984; Wagman et al. 1965).

Although the size principle of motor unit recruitment has been suggested to regulate the recruitment and rate coding of motor units (Henneman et al. 1974), it has further been suggested that the size principle may be invalid in dynamic free postural movements (Person 1974). The size principle may only apply to fixed isometric contractions and it has been considered that a more preferential recruitment of certain motor units could occur in explosive, free postural movements (Person 1974). Consequently, neural recruitment and rate coding may differ between isometric and dynamic tests of strength, which could conceivably affect the force output. Recent research has demonstrated clear differences in electromyogram (EMG) responses in the elbow flexors between isometric and dynamic muscle contractions at the same joint angles (Nakazawa et al. 1993). Consequently, motor unit activation may be different between isometric and dynamic contractions even if tests are structurally similar. The differing motor unit activation patterns would result in differing force outputs which may, in part, explain the low correlation between the structurally similar 1 RM bench press and the chest test. Furthermore, the eccentric contraction which precedes the concentric contraction in the dynamics tests would presumably also involve different afferent input from the muscle spindles which would effect the neural output. Wilson et al. (1991b) have reported increased integrated EMG activity of the triceps brachii and anterior deltoid muscles during the concentric phase of a 1-RM bench press that was preceded by an eccentric phase, in comparison to a 1 RM without prior stretch. This reflex-based neural augmentation associated with stretch-shorten cycle movements would not occur during a fixed isometric contraction.

Another neural limitation of isometric testing of leg extension force is that which occurs through the recruitment and cocontraction of the leg flexors (Baratta et al. 1988; Draganich et al. 1989). The cocontraction of the leg flexors, resulting in a counteracting torque, has been found to reduce the total net force output of the measured leg extension force by as much as 10% (Baratta et al. 1988). In the squat exercise cocontraction of the hamstring muscles must occur to stabilize the knee and, further, to extend the hip. However, the ability to control extraneous or unwarranted force production is a desirable skill which has been found to significantly affect strength development (Rutherford and Jones 1986). Such cocontraction of the leg flexors during squatting is essential but undesirable during the performance of the isometric leg test. Conceivably, this limitation of isometric testing, due to inappropriate cocontraction, may also occur in the chest test.

The fact that both isometric tests were performed unilaterally in comparison to the bilateral dynamic testing and training may also have affected the resultant relationship between the various measures of strength. Bilateral contractions would appear to offer greater scope for increases in force production, presumably through an enhancement of neural activation (Howard and Enoka, 1987). Hakkinen and Komi (1983) have reported enhanced neural activation in bilateral isometric leg extension tests but not in unilateral isometric tests, consequent to heavy resistance dynamic, bilateral squat training. This would indicate that differences in motor unit activation, and consequently force output, can be expected even within the same mode of testing when bilateral is compared to unilateral.

Mechanical considerations

One factor that clearly must be responsible for performance differences in an isometric test compared to a dynamic test is the use of elastic strain energy during the dynamic test. Elastic strain energy has been shown to contribute significantly to the load lifted in a bench press test, allowing on average a 14.5% increase in maximal 1-RM bench press (Wilson et al. 1991a). However, individual differences in flexibility and the compliance of the series elastic component would cause some individuals to be at a greater advantage than others during this dynamic test of strength, as they would be better able to utilize the elastic energy that contributes to the total force output (Wilson et al. 1992). Clearly the use of elastic energy would not be a significant factor during the isometric testing of the musculature and the relative ranking between subjects in the two tests could conceivably differ.

The VJ and most other dynamic sporting movements utilize a stretch-shorten cycle which would allow for the use of elastic energy to contribute significantly to performance. In contrast, isometric testing of the musculature would not allow for the use of elastic energy and conceivably may not reflect the muscles capabilities for dynamic situations. For example, Wilson et al. (1991a) have observed an increase of 18% in the impulse produced during the initial 370 ms of a maximal bench press that utilized a stretch-shorten cycle, compared to a bench press performed without prior stretch. Therefore, whilst isometric testing of the rate at which force can be developed appears entrenched in research methodology (Sale and Norman 1982; Hakkinen et al. 1985a, b; Young and Bilby 1993), it would appear that such monitoring does not correlate to dynamic speed-strength or power changes as it does not encompass important aspects of performance such as the utilization of elastic energy. Consequently, the validity of such tests to monitor training adaptations, which in real life situations are almost exclusively dynamic training induced, must be called into question.

Conclusions

The results of the relationships between the various measures of strength and speed-strength indicate that dynamic and isometric strength performances may correlate significantly, but that the extent of the relationship would indicate that performance may depend upon certain specific, not general, underlying mechanisms. Consequently, a generality of muscle function does not occur among differing test conditions and it would appear imprudent to extrapolate the results of one form of testing to another. The clear lack of a relationship of the training-induced changes in muscle function between the dynamic and isometric tests tends to indicate that different mechanisms underlie increased performance in the various measures of strength and speed-strength. Clearly, isometric and dynamic muscle actions are different physiological phenomenon (Dutcheau and Hainut, 1984). Therefore, in the testing of muscle function adherence to the principle of specificity should apply as strength and speed-strength appear specific, not general, in nature. Consequently, testing should involve conditions similar to those experienced by the individual, in terms of the structure of the test, the mode of contraction, the velocity of contraction and the load(s) or resistance(s) to be overcome.

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