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A Cross-Sectional Comparison of Different Resistance Training Techniques in the Bench Press

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ABSTRACT

Seven alternative resistance training techniques, performed using a bench press exercise, were compared with heavy weight training (HWT) on a number of variables. These resistance training techniques included isokinetics, eccentrics, functional isometrics, super slow motion, rest pause, breakdowns, and maximal power training. The main results were that eccentrics and isokinetics had significantly ($p < 0.05$) greater levels of force and integrated electromyography than HWT during the eccentric phase. Likewise, functional isometrics had significantly more force and breakdowns significantly higher triceps brachii electromyography than HWT in the concentric phase. Super slow motion and maximal power training both recorded significantly lower levels of force and integrated electromyography than HWT in each phase. However, super slow motion resulted in significantly greater time under tension (61.70 ± 2.12 vs. 21.15 ± 0.92 seconds) than HWT. Maximal power training recorded significantly greater levels of power production than HWT in both the eccentric and concentric phases. Although no alternative resistance training techniques were found to produce significantly greater levels of blood lactate response than HWT, maximal power training and eccentrics produced significantly lower levels.

Key Words: acute stresses, alternative weight training techniques, enhancement of muscular function

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Introduction

Resistance training now plays a major role in the conditioning programs of most sports, at least at the higher levels. It is used for many purposes, including weight gain via muscular hypertrophy, the enhancement of strength, power and/or strength endurance, and the prevention of or rehabilitation from injuries.

Heavy weight training (HWT) with loads of approximately 6 repetitions maximum (RM) has been shown to lead to significant increases in most aspects of muscular function (3, 5, 32). However, the results of some studies question the belief that HWT is the best form of training for strength (6, 33) or for athletic tests of power such as maximum water polo ball throw velocity (7), maximum punch velocity (36), or sprinting or jumping performance (41). Although periodization of resistance training has been used in an attempt to improve different aspects of muscular function, some of the alternative resistance training techniques assessed in this study may be more suited to improving different aspects of muscular function than HWT and hence could be used in specific phases of the annual periodized training plan.

Therefore, this study was conducted to gain a stress profile of 7 alternative resistance training techniques, including isokinetics (Isok), eccentrics (Ecc), functional isometrics (FI), super slow motion (SSM), rest pause (RP), breakdowns (BD), and maximal power training (MPT), and to compare these resistance training techniques to HWT.

Although many hypotheses could be tested in this study, it would be expected that Isok would produce significantly greater levels of force and integrated electromyography (IEMG) than HWT in each phase (16, 25), whereas Ecc would produce significantly greater levels of eccentric force and IEMG than HWT (22). Both FI and BD would also be expected to produce greater levels of force and IEMG in the concentric phase than HWT, based on the training studies of Berger and Hardage (6) and Giorgi et al. (13). Because of the greater expected time under tension associated with the use of SSM, it would be expected that SSM would result in greater levels of blood lactate response than HWT. It could also be hypothesized that SSM would produce significantly less, and MPT significantly greater, levels of power than HWT (41).

To test these hypotheses, we decided to use the bench press as the test exercise. The bench press has been extensively researched in cross-sectional (4, 27, 28, 31, 38) and longitudinal studies (5, 6, 13, 18). The cross-sectional research has shown that during a free-weight bench press, the bar undergoes both vertical and horizontal displacement and that with heavy loads a sticking point occurs relatively early in the concentric phase (28, 38). McGaw and Friday (27) also showed that free-weight bench presses at 60% of 1RM resulted in significantly greater IEMG levels than machine bench presses at 60% of 1RM, perhaps due to the greater stabilization required in the performance of the free-weight bench press.

Comparisons between HWT and some alternative resistance training techniques using the bench press have also been performed in cross-sectional (16, 25, 31) and longitudinal studies (6, 13, 18, 41).

The collection of these acute data, obtained with the use of the bench press, may have several benefits. First, it may suggest which resistance training techniques have the greatest potential for improving different aspects of muscular function. Hence, this may enable practitioners in the area of resistance training to increase the effectiveness of their resistance training programs by using resistance training techniques that maximally stress the neuromuscular system. Second, by determining the acute stresses these resistance training techniques impose on the system, it may be possible to elucidate which acute stresses are most important for improving the different aspects of muscular function. However, it must be remembered that the results from this study were obtained with the bench press and therefore may vary with other exercises.

Methods

Subjects

Twelve weight-trained men, between the ages of 21 and 35 years who participated in such sports as rugby union, power lifting, and bodybuilding and possessed a 1RM bench press at least equal to their body mass, were recruited for this study. Each of these subjects had been consistently training with weights (at least 2–5 sessions per week), emphasizing multijoint free-weight exercises such as the squat and bench press, for a minimum of 2 years. These criteria ensured that all subjects were at least relatively experienced weight trainers.

The group's means ($\pm$ *SD*) for age, height, mass, 1RM bench press, and training experience were 25.4 $\pm$ 4.8 years, 177.6 $\pm$ 4.6 cm, 90.6 $\pm$ 14.5 kg, 126.9 $\pm$ 46.9 kg, and 6.1 $\pm$ 4.0 years, respectively.

This study was approved by the Ethics Committee at Southern Cross University, and all subjects read and signed an informed consent form before participation in the study.

Testing Procedures

Each subject was familiarized with the alternative resistance training techniques during 2 familiarization sessions, with the use of the bench press exercise. Each familiarization session entailed the performance of 2 sets of each of the alternative resistance training techniques. However, if the investigator felt that a subject was having trouble mastering a given technique, additional practice of that technique was performed until the investigator was confident that the subject was performing that technique according to the performance guidelines outlined in Table 1.

Table 1 shows the loads used and the performance guidelines for the resistance training techniques assessed in this study. All resistance training techniques were assessed with 1 set of approximately 6 repetitions to failure except Isok and MPT, which were limited to 6 repetitions, each performed with maximal effort throughout the set. This was necessary because Isok and MPT were techniques that could be continued in a submaximal manner for an indefinite period.

During these familiarization sessions, the 1RM and 6RM bench press loads were also determined, with the former being assessed at the commencement of the first session and the latter at the commencement of the second session. The procedures for the 1RM and 6RM tests were similar to those adopted by Wilson et al. (39). During the familiarization and testing sessions, each repetition of the bench press had to be performed strictly. This entailed no bouncing of the bar off the chest and the head, shoulders, and buttocks remaining stationary on the bench and the feet on the footrest on the bench. Subjects were instructed to position themselves on the bench so that the bar was directly over the nipples and to grip the bar so that when the elbow angle was 90° the wrists were directly over the elbows.

During the 2 testing sessions, each subject performed 4 of the 8 resistance training techniques in a random order. However, the Ecc and Isok tests were conducted last on either testing session because heavy eccentric exercise has been shown to lead to significantly greater and longer-lasting fatigue than concentric exercise (9). Each subject was given 20 minutes rest between each test, so fatigue would not significantly disadvantage the results of the resistance training techniques that were tested at the completion of the testing sessions.

Equipment

All testing and familiarization sessions were conducted in the Plyometric Power System (PPS) (Norsearch, Lismore, Australia). The PPS is a modified Smith Machine that allows kinematic data to be easily collected. Various additional features of the PPS also allowed the performance of some of the alternative resistance training techniques. For example, the PPS has been instrumented with a 4-kW AC motor so that eccentric and concentric isokinetic actions can be performed for linear, multijoint exercises such as squats and bench presses (42). The motor, which was controlled by an AC induction controller (PDL Electronic, Napier, New

Table 1. Performance characteristics and description of resistance training techniques.

Training technique	Load	Other guidelines
Heavy weight training	6RM	NA
Isokinetics	NA	Performed at 0.2 ms^{-1} for each eccentric and concentric phase; only 6 repetitions performed.
Eccentrics	110% of 1RM	4 s per eccentric phase; no concentric phase.
Functional isometrics	6RM	Normal isoinertial lift but with a 2-s MVIC at an elbow angle of 160°.
Super slow motion	55% of 1RM	5 s for each eccentric and concentric phase; attempt to maintain constant velocity.
Rest pause	6RM	Normal isoinertial lift with a 2-s unloaded rest period at the end of each concentric phase.
Breakdowns	95, 90, 85, 82.5 and 80% of 1RM	Normal isoinertial lift with load reduced each repetition until 80% of 1 RM was reached.
Maximal power training	30% of 1RM	Bar explosively thrown and released into the air; As the bar descends, it is caught with outstretched arms; resulting in a rapid eccentric action prior to the next concentric action; only 6 repetitions were performed.

* RM = repetition maximum; MVIC = maximum voluntary isometric contraction.

Zealand), was able to go from zero to maximum torque within a few milliseconds (42). Because of the standard acceleration of the bar, it has been shown that the bar's velocity has stabilized at the preset velocity of 0.4 $m{\cdot}s^{-1}$ within 200 ms during the performance of a variety of concentric squats (42).

The braking system incorporated into the PPS also allowed the unloaded rest periods for RP to be performed (17). Additionally, mechanical stops could be positioned on the PPS so that each subject could perform a maximum voluntary isometric contraction (MVIC) at an elbow angle of 160° during the performance of FI (13).

Although the authors acknowledge the differences inherent between performing bench presses in a free-weight or machine environment (27), because of the technology adopted in this study, it was not possible to examine all techniques in a free-weight environment and hence a machine bench press was examined in all instances.

Vertical force was recorded on a Kistler Force Platform (type 9287A, Winterthur, Switzerland). The force data that were sampled at a rate of 1000 Hz were collected for the duration of each set of each resistance training technique by a DAS16 analogue to digital card installed in a 486 IBM compatible computer. As seen in Figure 1, the bench press bench was securely bolted onto the force platform so that the entire weight of the bench was directed through the force platform. Before the commencement of any test, the force platform was reset to zero with the subject lying prone on the bench, so that only the vertical muscular forces were recorded during the test.

An AMLAB II beta release (AMLAB International, North Ryde, Sydney, Australia) project was used to coordinate the collection of all the data, except the blood lactate concentrations, and to perform some standard calculations on the raw data. The methods used for these calculations will be explained in more detail in a later section.

Electromyography

The apparent belly of the sternal head of the pectoralis major and the long head of the triceps brachii were selected as sites for EMG electrode application, since these muscles are 2 of the prime movers during the bench press and have been used in previous EMG studies of the bench press (4, 27, 31, 38). The belly of these muscles were chosen as the site for EMG placement, because this has been shown to maximize the amount of EMG activity detected (43), which may assist in showing significant differences between the techniques.

The preamplified silver-silver EMG surface electrodes were positioned parallel to the direction of the fibers of the previously mentioned muscles. Before the application of the electrodes, the skin was prepared. This entailed shaving of the area, wiping with alcohol, and abrading the area with fine emery paper. Signa

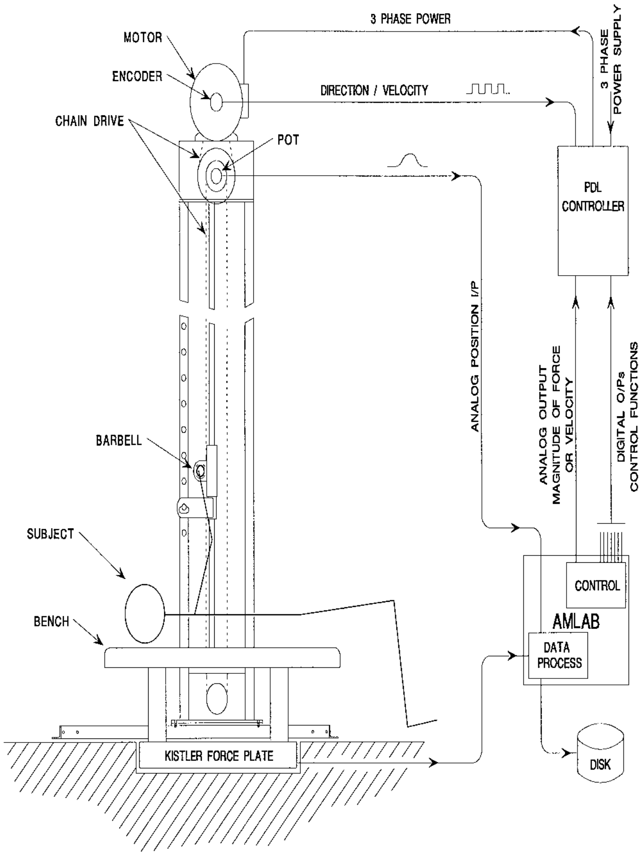

Figure 1. Schematic of the isokinetic bench press and associated data collection devices.

Gel electrode gel (Parker Laboratories, Orange, USA) was then applied to the electrodes, which were then positioned on the appropriate muscles. Using a permanent marking pen, an outline of the EMG electrodes was drawn on the muscles so the placement of the electrodes would be as similar as possible for the 2 testing sessions.

IEMG and MVIC Reliability

Because data were collected from 2 separate testing sessions, it was necessary to determine the reliability of the most important dependent variables. Therefore, peak MVIC force at an elbow angle of 110° and the peak pectoralis major and triceps brachii IEMG obtained from the MVIC were selected. Coefficient of variation (V) and correlation coefficients (r) were calculated for each of the dependent variables. These results showed that peak MVIC was the most reliable measure, with a V of 7.07% and a highly significant ($p < 0.01$) correlation ($r = 0.93$). The IEMG data obtained from the MVIC were also reliable, with the pectoralis major obtaining a V of 16.05% and a highly significant ($p < 0.01$) correlation ($r = 0.81$) and the triceps brachii a V of 8.77% and a significant ($p < 0.05$) correlation ($r = 0.59$). These results appeared consistent with the values reported in reviews on interday reliability of peak isometric force (40) and peak IEMG (24).

Blood Lactate Measurements

Blood lactate levels were taken immediately before and 3 minutes after the completion of each of the resistance training techniques. A small sample of blood was taken from a fingertip by Microtainer Brand Safety Flow Lancets. Sufficient blood from these incisions was allowed to flow into a Brand NH^4 heparinized capillary tube. From the capillary tube, 0.02 ml of blood was added to a labeled Eppendorf tube filled with buffer at a ratio of 1:3 (blood to buffer). These samples were then placed in refrigeration at approximately 5°C. Within 24 hours of collection, these blood samples were analyzed with the use of the YSI 1500 Lactate Analyzer (Yellow Springs Instrument Co., Yellow Springs, OH).

Data Analysis

Means for all the dependent variables were calculated by the AMLAB project. These were calculated between 20–80% of the total range of motion for each resistance training technique, so any inconsistencies in performance toward the extremities of motion did not affect the data obtained. The only exception to this rule was for FI. This was due to the fact that the only difference between FI and HWT was the MVIC at an elbow angle of 160°. Hence, for FI, the means were calculated from 20–100% of total range of motion.

Power was calculated by the AMLAB project by simultaneously multiplying force and velocity. Velocity was calculated through the AMLAB project by differentiating the smoothed positional data with respect to time. The positional data were smoothed via the use of a low-pass filter with a cutoff frequency of 39.818 Hz.

The raw EMG signal was recorded at a rate of 1000 Hz and bandpass filtered (lower and upper cutoffs at 10.282 and 478.986 Hz, respectively), full wave rectified, and then integrated for 40 milliseconds to give IEMG. At the beginning of each testing session, the IEMG data were normalized by use of a MVIC in the bench press at an elbow angle of 110°. All IEMG data from that testing session were then expressed as a percentage of this peak IEMG achieved during the MVIC.

The blood lactate response to each resistance training technique was defined as the difference between the pretest and 3-minute posttest blood lactate levels. This was done because the pretest blood lactate levels may not have been similar for all the resistance training techniques.

Time under tension was defined as the total time in which the muscles were applying force to the bar during the performance of each of the tests. This measurement was recorded by the AMLAB project.

Although the data were recorded for all repetitions of all tests, only the first, middle, and last repetition of each test was used for further analysis. In addition, each repetition's results were subdivided into eccentric and concentric phases.

Table 2. Mean eccentric force for all 8 resistance training techniques (mean ± *SD*).

Technique	First repetition	Middle repetition	Last repetition
Heavy weight training (HWT)	1,069.18 ± 370.42	1,128.78 ± 390.57	1,117.80 ± 368.44
Isokinetics	1,385.60 ± 453.75*	1,420.33 ± 695.90*	1,250.38 ± 420.71*
Eccentrics	1,377.45 ± 496.14*	1,380.11 ± 508.29*	1,356.31 ± 484.21*
Functional isometrics	1,015.52 ± 298.16	1,060.89 ± 345.85***	1,058.52 ± 358.88**
Super slow motion	691.93 ± 256.32**	701.92 ± 247.03**	700.28 ± 251.00**
Rest pause	1,056.40 ± 353.72	1,063.98 ± 365.97**	1,057.33 ± 354.68**
Breakdowns	1,211.45 ± 420.92*	1,097.33 ± 371.06	1,044.71 ± 351.76**
Maximal power training	412.12 ± 136.78**	762.74 ± 199.87**	774.34 ± 184.44**

* Significantly more than HWT ($p < 0.01$).
** Significantly less than HWT ($p < 0.01$).
*** Significantly less than HWT ($p < 0.05$).

Table 3. Mean eccentric pectoralis major integrated electromyogram (% maximum voluntary isometric contractions) for all 8 resistance training techniques (mean ± *SD*).

Technique	First repetition	Middle repetition	Last repetition
Heavy weight training (HWT)	57.65 ± 12.09	69.23 ± 17.17	73.95 ± 15.80
Isokinetics	64.93 ± 13.56	82.20 ± 14.52*	84.90 ± 14.86
Eccentrics	68.75 ± 16.20*	75.74 ± 15.45*	85.43 ± 13.06*
Functional isometrics	54.69 ± 15.05	63.92 ± 15.43	69.84 ± 12.65
Super slow motion	43.68 ± 14.76**	47.35 ± 17.24**	56.50 ± 20.36**
Rest pause	56.45 ± 14.36	61.43 ± 15.48	60.56 ± 16.48**
Breakdowns	60.00 ± 13.74	72.41 ± 16.25	72.58 ± 14.74
Maximal power training	30.07 ± 13.05**	47.07 ± 17.97**	51.44 ± 14.11**

* Significantly more than HWT ($p < 0.01$).
** Significantly less than HWT ($p < 0.01$).
*** Significantly less than HWT ($p < 0.05$).

Statistical Analysis

A multivariate analysis of variance (MANOVA) was used to determine if there were any significant differences between the resistance training techniques on any of the dependent variables. All the assumptions for the MANOVA were satisfied. If any significant differences were found, a Bonferroni test using Helmert contrasts was performed to see if any of the alternative resistance training techniques were significantly different to HWT. An α level of 0.05 was used for all comparisons.

To obtain a statistical power of 90% (i.e., to be 90% confident that no type II error would occur with the use of the MANOVA), a sample size of 12 was required (23).

Results

Eccentric

As seen in Tables 2–4, Ecc and Isok enabled significantly greater force and IEMG to be produced in the eccentric phase than HWT. These Tables also showed that SSM and MPT produced significantly lower levels of eccentric force and IEMG than HWT. It was also apparent that FI produced significantly lower levels of eccentric triceps brachii IEMG than HWT.

Table 5 revealed that MPT produced significantly greater eccentric power than HWT, whereas all the other alternative resistance training techniques produced significantly lower levels of eccentric power than HWT on at least one of the analyzed repetitions.

Concentric

Unlike the results for the eccentric phase, the differences between the alternative resistance training techniques and HWT in the concentric phase were not as consistent. Table 6 revealed that only FI produced significantly greater levels of concentric force than HWT across all repetitions. Table 6 also showed that Isok, SSM, and MPT produced significantly lower levels of concentric force than HWT on most repetitions. Table 7 revealed that SSM, RP, and MPT generally generated lower levels of pectoralis major IEMG than HWT. Table 8 showed that although BD produced significantly greater levels of concentric triceps brachii IEMG, Isok and SSM resulted in significantly lower levels of triceps brachii IEMG than HWT.

Table 4. Mean eccentric triceps brachii integrated electromyogram (% maximum voluntary isometric contractions) for 8 resistance training techniques (mean ± *SD*).

Technique	First repetition	Middle repetition	Last repetition
Heavy weight training (HWT)	48.97 ± 14.41	60.88 ± 14.88	64.41 ± 17.24
Isokinetics	64.75 ± 16.89*	76.15 ± 18.10*	77.31 ± 11.19*
Eccentrics	68.92 ± 15.78*	73.45 ± 16.72*	72.88 ± 14.03*
Functional isometrics	45.46 ± 17.68	51.66 ± 18.89***	54.22 ± 17.82**
Super slow motion	33.24 ± 13.97**	39.21 ± 13.42**	41.51 ± 15.17**
Rest pause	53.46 ± 13.16	56.47 ± 15.91	56.58 ± 19.62
Breakdowns	59.22 ± 18.32*	64.51 ± 16.41	66.41 ± 19.37
Maximal power training	25.17 ± 10.60**	34.86 ± 14.08**	39.02 ± 13.37**

* Significantly more than HWT ($p < 0.01$).
** Significantly less than HWT ($p < 0.01$).
*** Significantly less than HWT ($p < 0.05$).

Table 5. Mean eccentric power for all 8 resistance training techniques (mean ± *SD*).

Technique	First repetition	Middle repetition	Last repetition
Heavy weight training (HWT)	322.86 ± 123.50	483.91 ± 190.15	417.78 ± 119.96
Isokinetics	289.53 ± 93.56	268.14 ± 92.25**	261.94 ± 87.37**
Eccentrics	112.70 ± 52.06**	108.50 ± 53.47**	161.57 ± 117.12**
Functional isometrics	275.71 ± 139.59	256.92 ± 78.93**	234.23 ± 77.43**
Super slow motion	43.21 ± 12.29**	43.10 ± 14.57**	45.84 ± 17.88**
Rest pause	272.37 ± 103.13	341.88 ± 141.30***	298.33 ± 133.09***
Breakdowns	338.15 ± 131.75	361.32 ± 87.24**	346.11 ± 98.81
Maximal power training	196.45 ± 71.12	738.97 ± 176.51*	777.88 ± 160.27*

* Significantly more than HWT ($p < 0.01$).
** Significantly less than HWT ($p < 0.01$).
*** Significantly less than HWT ($p < 0.05$).

Table 6. Mean concentric force for all 8 resistance training techniques (mean ± *SD*).

Technique	First repetition	Middle repetition	Last repetition
Heavy weight training (HWT)	1,166.57 ± 353.98	1,147.02 ± 345.26	1,131.91 ± 364.46
Isokinetics	1,147.85 ± 414.04	1,020.92 ± 388.15***	915.20 ± 463.33***
Eccentrics	NA	NA	NA
Functional isometrics	1,469.64 ± 367.15*	1,432.63 ± 346.14*	1,284.71 ± 339.57*
Super slow motion	770.70 ± 252.46**	778.87 ± 251.59**	769.72 ± 255.09**
Rest pause	1,148.59 ± 336.44	1,134.31 ± 330.88	1,100.79 ± 319.75
Breakdowns	1,291.37 ± 411.70*	1,148.22 ± 361.74	1,011.33 ± 323.44***
Maximal power training	807.13 ± 207.08**	783.56 ± 217.46**	740.97 ± 196.92**

* Significantly more than HWT ($p < 0.01$).
** Significantly less than HWT ($p < 0.01$).
*** Significantly less than HWT ($p < 0.05$).

The results of Table 9 showed that although MPT produced significantly greater levels of concentric power than HWT, all the other resistance training techniques produced levels of concentric power that were significantly lower than HWT.

Overall

Table 10 revealed that the time under tension for Ecc and SSM was significantly greater than HWT, whereas MPT was significantly lower, and that no alternative resistance training technique was significantly differ-

Table 7. Mean concentric pectoralis major integrated electromyogram (% maximum voluntary isometric contractions) for all 8 resistance training techniques (mean ± *SD*).

Technique	First repetition	Middle repetition	Last repetition
Heavy weight training (HWT)	76.21 ± 15.59	91.29 ± 18.82	92.94 ± 14.72
Isokinetics	75.77 ± 15.29	84.85 ± 18.64	87.77 ± 18.16
Eccentrics	NA	NA	NA
Functional isometrics	75.06 ± 17.95	85.16 ± 16.66	86.45 ± 16.44**
Super slow motion	62.98 ± 16.52*	74.29 ± 16.75*	82.36 ± 14.95*
Rest pause	71.45 ± 14.98	78.33 ± 13.88**	81.60 ± 12.09*
Breakdowns	79.92 ± 27.60	92.14 ± 26.10	94.09 ± 25.05
Maximal power training	63.65 ± 21.32*	73.22 ± 23.72*	79.05 ± 18.65*

* Significantly less than HWT ($p < 0.01$).
** Significantly less than HWT ($p < 0.05$).

Table 8. Mean concentric triceps brachii integrated electromyogram (% maximum voluntary isometric contractions) for all 8 resistance training techniques (mean ± *SD*).

	First repetition	Middle repetition	Last repetition
Heavy weight training (HWT)	83.89 ± 5.90	89.12 ± 8.34	92.98 ± 9.01
Isokinetics	76.04 ± 14.20**	75.56 ± 21.53**	79.76 ± 11.23*
Eccentrics	NA	NA	NA
Functional isometrics	83.00 ± 11.81	83.97 ± 15.59	93.68 ± 17.45
Super slow motion	53.58 ± 17.72*	63.32 ± 14.64*	74.32 ± 16.79*
Rest pause	81.95 ± 9.86	86.49 ± 10.10	84.63 ± 14.40
Breakdowns	92.81 ± 13.04***	98.88 ± 13.48***	97.55 ± 13.11
Maximal power training	82.56 ± 16.49	86.38 ± 16.54	90.02 ± 19.14

* Significantly less than HWT ($p < 0.01$).
** Significantly less than HWT ($p < 0.05$).
*** Significantly more than HWT ($p < 0.01$).

Table 9. Mean concentric power for all 8 resistance training techniques (mean ± *SD*).

	First repetition	Middle repetition	Last repetition
Heavy weight training (HWT)	353.81 ± 123.13	291.86 ± 99.31	104.71 ± 42.38
Isokinetics	239.66 ± 86.03*	213.13 ± 83.00*	190.00 ± 98.52****
Eccentrics	NA	NA	NA
Functional isometrics	290.90 ± 92.03**	206.74 ± 39.20*	105.95 ± 60.01
Super slow motion	42.91 ± 13.98*	46.00 ± 15.11*	39.79 ± 13.25*
Rest pause	313.07 ± 116.74	255.96 ± 109.19	92.40 ± 47.66
Breakdowns	251.44 ± 85.19*	235.05 ± 78.15**	113.48 ± 80.19
Maximal power training	934.88 ± 274.93***	932.12 ± 301.38***	854.50 ± 275.87***

* Significantly less than HWT ($p < 0.01$).
** Significantly less than HWT ($p < 0.05$).
*** Significantly more than HWT ($p < 0.01$).
**** Significantly more than HWT ($p < 0.05$).

ent to HWT on the number of repetitions performed. Table 11 showed that although Ecc and MPT produced significantly lower levels of blood lactate response than HWT, no resistance training technique produced a significantly greater response than HWT.

Discussion

The results as shown in Tables 2–4 tended to suggest that Ecc and Isok imposed a greater overload on the eccentric capabilities of the musculature than HWT. As

Table 10. Time under tension and repetitions performed for 8 resistance training techniques (mean ± *SD*).

Technique	Time under tension (s)	Repetitions performed per set
Heavy weight training (HWT)	21.15 ± 0.92	6.00 ± 1.11
Isokinetics	21.50 ± 0.57	6.00 ± 0.00
Eccentrics	29.95 ± 1.48*	5.58 ± 1.44
Functional isometrics	21.40 ± 1.56	4.25 ± 0.97
Super slow motion	61.70 ± 2.12*	5.33 ± 1.15
Rest pause	27.35 ± 1.48	7.33 ± 2.14
Breakdowns	27.60 ± 2.83	6.42 ± 1.16
Maximal power training	6.60 ± 0.14**	6.00 ± 0.00

* Significantly greater than HWT ($p < 0.05$).
** Significantly less than HWT ($p < 0.05$).

Table 11. Blood lactate response to various resistance training techniques (mean ± *SD*).

Technique	Blood lactate response (mM)
Heavy weight training (HWT)	2.70 ± 1.88
Isokinetics	2.87 ± 1.37
Eccentrics	1.40 ± 0.73*
Functional isometrics	1.59 ± 1.08
Super slow motion	3.01 ± 1.70
Rest pause	2.95 ± 2.10
Breakdowns	3.20 ± 1.14
Maximal power training	0.75 ± 0.37**

* Significantly less than HWT ($p < 0.05$).
** Significantly less than HWT ($p < 0.01$).

such, Ecc and Isok may be able to be used to increase eccentric muscle function to a greater extent than HWT. Since eccentric strength has been shown to discriminate between downhill skiers of varying ability (1) and to be significantly correlated to performance in running agility tests (2), the use of Ecc and Isok may enhance performance in these pursuits to a greater extent than currently obtained with HWT. Additionally, sports in which highly loaded stretch shorten cycles regularly occur, such as the jumping events in athletics and gymnastics, may also benefit from the addition of heavy eccentric training, such as that found in Ecc or Isok.

Both Ecc and Isok may also prove quite useful in hypertrophy training. Since Ecc had significantly greater levels of force and time under tension than HWT, it may represent a superior training technique to HWT in enhancing muscular hypertrophy (26, 29). This has been supported by Hakkinen and Komi (15), who reported that the addition of heavy eccentric training to the training program of relatively experienced weight trainers resulted in significantly greater gains in bench press strength and muscular hypertrophy than HWT.

Although Ecc had a significantly greater level of time under tension than HWT, it also had a significantly lower blood lactate response. Therefore, it does not appear that Ecc would be superior to HWT in its ability to develop strength endurance. With the greater time under tension for Ecc, it may be thought that Ecc should also produce greater quantities of lactate. However, the lower blood lactate response to Ecc was not unexpected, since eccentric exercise has been shown to have decreased oxygen consumption and energy use than concentric exercise (10). This is thought to be due to the greater use of the elastic components of the neuromuscular system during eccentric exercise (21).

In addition, Isok may prove more useful for hypertrophy training than HWT, although the results are somewhat mixed. As with Ecc, Isok produced significantly greater levels of eccentric overload than HWT. However, Isok was found to produce significantly lower levels of concentric force and IEMG on the latter repetitions than HWT. This was unexpected since previous studies have shown that isokinetic exercise produces significantly greater levels of force than HWT in the concentric phase (16, 25). However, the present study assessed Isok with 6 continuous cycles of eccentric-concentric isokinetic actions. Hence, a greater level of fatigue may have occurred with Isok, therefore leading to large reductions in concentric force production toward the end of the set.

With respect to improving levels of strength endurance, the acute data presented in this study do not suggest that Isok would be superior to HWT.

As seen in Tables 5 and 9, MPT enabled significantly greater levels of power to be developed in the eccentric and concentric phases than HWT. Since training at higher power outputs appears to significantly increase muscular power (20, 41), MPT may be an ideal form of power training.

Although no training studies appear to have assessed gains in hypertrophy from MPT, it also appears unlikely, based on the acute stresses measured in this study, that MPT would result in greater gains in hypertrophy than HWT (26, 29). On the basis of the acute data presented in this article, MPT may even result in significantly lower levels of muscular hypertrophy than HWT.

Regarding the enhancement of strength endurance, MPT would not appear to be as effective as HWT. This is due to the significantly lower levels of time under tension, blood lactate response, IEMG, and force production recorded during the performance of MPT.

Like MPT, most results revealed that SSM resulted in significantly lower levels of stress on the neuromuscular system than HWT (Tables 2–9). This suggests that SSM would be inferior to HWT in improving most aspects of muscular function. However, SSM resulted in significantly greater levels of time under tension than HWT. Since time under tension appears to be an important stimulus for the enhancement of hypertrophy (29) and strength endurance (3), SSM may be best used to increase these aspects of muscular function. However, because many activities in sports that require strength endurance must be performed at relatively high velocities, SSM may not be specific to these requirements because of the slow velocity of execution (19).

There appears to be even less evidence to support the use of SSM in the enhancement of strength and power. Because of the low level of eccentric stress imposed on the neuromuscular system by SSM, it would suggest that eccentric function would not improve if SSM was used as the foundation of the training program. Concentric function would also be unlikely to significantly increase as the force and power outputs appeared to be too low to cause gains in strength (26) or power (20). Since a velocity specificity is known to occur (19), the use of SSM may even cause decrements in performance of high-velocity activities. As such, SSM would not be specific to the needs of almost any athlete.

Table 6 showed that FI allowed the production of significantly greater levels of force than the other training techniques in the concentric phase. Since force has been shown to be an important variable for improving strength (11, 26), the use of FI may improve 1RM strength to a greater degree than HWT. This contention has been supported by the findings of Jackson et al. (18) and O'Shea and O'Shea (33), and to a lesser extent by Giorgi et al. (13), who found significant differences between the strength improvement for the strongest individuals in the FI and HWT groups.

In addition, FI may prove to be a significantly better training technique with which to increase muscular hypertrophy than HWT. This is because FI allowed significantly greater concentric force production and similar levels of IEMG, eccentric force, and time under tension compared with HWT (Tables 2–4, 6–8, and 10). However, to our knowledge, no studies have examined this contention to date.

Regarding the ability of FI to increase muscular power, it does not appear that FI would result in greater improvements than HWT, due to the significantly lower level of power output with FI. This tends to support the findings of the training studies to date. These studies have shown either no increases in power (13) or significant increases in power that were significantly less than those obtained with HWT (33).

Regarding strength endurance, the acute stresses do not suggest that FI would be significantly better than HWT in promoting gains in strength endurance. Since no studies, to our knowledge, have examined this to date, there is also no evidence to contradict this contention.

Although the use of BD has been shown to increase 1RM strength to a significantly greater extent than HWT (6), the acute response to BD and HWT was relatively similar (Tables 2–4, 6–8, and 10). On the first repetition, BD resulted in significantly greater eccentric and concentric force and triceps brachii IEMG than HWT. Similar levels of force and IEMG occurred on the middle repetition, whereas significantly lower levels of force were produced on the last repetition. In addition, no significant differences were observed between these training techniques on time under tension or blood lactate response. Hence, BD and HWT produced similar levels of force, time under tension, and blood lactate response during a set, but BD appeared to stress the neuromuscular system to a greater extent as seen in the IEMG data. This greater IEMG for BD appears to support a hypothesis put forward by Rooney et al. (34), who stated that the greater degree of fatigue associated with BD may have been responsible for the results reported by Berger and Hardage (6).

Therefore, in addition to perhaps being superior to HWT in promoting increases in strength, BD may also be significantly better than HWT in promoting gains in hypertrophy. This would be primarily due to the significantly greater level of IEMG that BD imposes on the system than HWT. The high level of stress that is imposed on the neuromuscular system for similar periods to HWT suggests that a greater proportion of available motor units were recruited and hence may have been stimulated to undergo hypertrophy (14).

The evidence also suggests that BD would be as good as, if not better than, HWT in promoting gains in strength endurance. However, the performance of BD could be altered to increase its effectiveness in enhancing strength endurance. This would simply involve a greater number of reductions in weight and hence the performance of a greater number of repetitions. Wilson (37) suggests that training in a style similar to this would be an ideal method to increase strength endurance, since high loads are initially used and a large number of repetitions can be performed, thereby ensuring a high level of muscular effort throughout the set, time under tension, and blood lactate production. Because a high level of maximal strength is also thought to be beneficial for strength endurance performance (37), BD may be superior to the low-load, high-repetition training that is commonly performed in strength endurance training, since it would stimulate gains in maximal strength to a greater extent than current practices (3, 6).

Regarding the ability of BD to increase muscular power, the acute stresses shown in this study tend to suggest that BD would not be better than HWT and would perhaps be even worse. This is due to the significantly lower levels of power produced by BD compared with HWT. Since BD recorded significantly greater levels of force than HWT, the significantly lower levels of power must have been due to BD being conducted at significantly lower velocities than HWT. This also suggested that BD would not be ideal for promoting gains in explosive power.

Like FI and BD, RP did not appear to be too different from HWT on most acute stresses. As expected, force levels were similar between RP and HWT, since the loads used by these techniques were identical. Time under tension was also not significantly different between the techniques, but the increase in IEMG for RP during a set tended to be of a smaller magnitude than HWT. On the last and sometimes the middle repetition, HWT actually had significantly greater levels of IEMG than RP.

The significantly lower levels of IEMG on some repetitions for RP were unexpected, since the same load was used for HWT and RP and both were performed to failure. This suggested that some aspect of the 2-second rest between repetitions in RP was responsible for the difference in IEMG response. A study by Moritani et al. (30) may help to explain these findings. Moritani et al. (30) reported that by occluding the blood flow during isometric hand gripping significantly greater increases in motor unit spike amplitude, motor unit spike frequency, and root mean square of the EMG signal occurred compared with identical contractions without blood occlusion. These findings were interpreted to suggest that by decreasing the blood flow to an exercising muscle significant increases in motor unit recruitment and/or rate coding are required to maintain force output (30).

These IEMG data may suggest that RP would not be significantly better than HWT in promoting gains in strength and hypertrophy and could perhaps be even significantly worse. In addition, the effect of the 2-second pause between repetitions is not really known. Because some authorities believe that constant tension on a muscle is important for the enhancement of muscular hypertrophy (8), this would also tend to suggest that RP would be inferior to HWT in promoting increases in this aspect of muscular function. However, because of the small rest periods between repetitions, greater loads could be used for the same number of repetitions as performed with HWT. This style of performance may be more suited to the enhancement of strength because of the greater levels of force produced (11, 26).

These findings may also suggest that RP training could be used successfully by many athletic groups for specific strength endurance training, since it may teach the body to quickly recover between brief near-maximal contractions. This accelerated recovery may involve several peripheral factors, which include the partial replenishment of the adenosine triphosphate and phosphocreatine (ATP-PC) stores and the removal of some lactate and hydrogen ions from the working muscles (35).

Regarding the enhancement of power, the level of power production during RP was not significantly different from that obtained with HWT. Hence, it does not appear that RP would cause significantly greater gains in muscular power than HWT.

Practical Application

The acute data collected in this study from the bench press showed that most alternative resistance training techniques appeared to be significantly greater than HWT on some of the acute variables. Therefore, each alternative resistance training technique may prove to be better than HWT in its ability to improve at least one aspect of muscular function. However, the use of these techniques should be matched to the needs of the athletes and in most cases only used with relatively experienced weight-trained athletes.

Isok may be able to be used for various uses, if the athlete has access to an isokinetic dynamometer. By using Isok, the eccentric phase can be overloaded and high velocities can also be performed effectively. Hence, Isok may be quite useful in increasing eccentric strength and power. Athletes who could find this useful may include downhill skiers and athletes in sports that require the frequent performance of powerful jumping motions, e.g., athletics, gymnastics, or basketball.

Ecc appears most useful for increasing strength (particularly eccentric strength) and muscular hypertrophy. Hence, it may be used by a variety of athletes, especially in the off-season, if attempting to increase muscle mass.

FI appears most useful in increasing strength and perhaps muscular hypertrophy. Hence, it would also appear to be useful in the off-season phase of training. Linemen in gridiron and forwards in rugby union and rugby league may also benefit from this technique, since aspects of these games (i.e., blocking and scrummaging) involve a concentric contraction followed by an isometric contraction at collision. This is exactly what happens in FI, and it can therefore be used successfully to teach players to continue pushing forcefully at impact so that their opponent will be forced backward.

It also appears that power lifters and weightlifters could successfully use this technique, especially if the MVIC was applied in the sticking region. This would take advantage of the angle specificity of isometric training (12) and possibly lead to the greatest gains in 1RM performance.

It is unknown whether SSM would prove to be better than HWT in improving any aspects of muscular function. However, because of the low loads used and the controlled contractions, it may prove beneficial in the early stages of rehabilitation.

On most of the acute data, RP appeared similar to HWT. However, it did appear to allow a greater level of time under tension due to the performance of more repetitions. Hence, it could be used successfully for strength endurance training.

Like Ecc and FI, BD appears to offer a greater stimulus on the system to improve in strength and perhaps muscular hypertrophy. Therefore, it could also be used to good effect in the off-season for most athletes. For athletes participating in high-intensity events of relatively short duration, such as middle distance runners, swimmers, cyclists, wrestlers, and boxers, BD could be used as a stressful form of strength endurance training for large compound exercises such as squats by continually stripping weight off the bar until the athlete can no longer perform even one contraction with the bar.

In addition, BD may be used to good effect by power lifters because of biomechanical specificity, in that lighter loads have different bar profiles and activation levels than maximal loads (38).

For athletes involved in most types of powerful stretch shorten cycle activities, MPT appears to be ideal. Athletes requiring great vertical jump height, such as basketball players, volleyball players, and high jumpers, can use loaded squat jumps to significantly improve vertical jump performance. Upper body movements, such as bench press or shoulder press throws, can also be performed. These exercises may be specific to the needs of athletes such as the shotputter and linemen in gridiron. Since MPT is used to increase power, it should be used primarily in the preseason and in-season phases of training.

Although loads of approximately 30% of 1RM have been shown to maximize power output, other loads can also be used to more closely simulate the force and velocity characteristics of a variety of athletic movements. For example, a high jumper would use a lower percentage of 1RM for squat jumps than a weightlifter because of the differing demands of these sports.

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