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A Comparison of Muscle Activity Between a Free Weight and Machine Bench Press

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Reference Data

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ABSTRACT

This study calculated IEMG values during the ascent and descent phases of the bench press and compared the values between lifts performed with free weights versus a guided weight machine. In Phase 1 of the study the 1-RM on each mode was determined for each subject. In Phase 2, EMG data were collected from five muscles of the upper extremity while each subject completed five trials at 80% of 1-RM and five trials at 60% of 1-RM for each mode. Linear envelopes were created from the EMG data of each trial, and IEMG values were calculated during the descent and ascent phases of each trial. Planned comparisons were used to compare mean IEMG values between the two loads within the same mode, and between the two modes at both the 60% and 80% loads. Results suggested greater muscle activity during the free-weight bench press, especially at the 60% 1-RM load, although there were notable differences among the patterns of individual subjects.

Key Words: weight training, electromyography, variability

Introduction

Muscular strength has been shown to increase when a progressive resistance program is followed, regardless of whether exercises are performed with free weights or machines (4, 16). Although neither mode has been found superior, advantages and disadvantages to both modes have been proposed. Since free weight exercise requires controlling the bar in three-dimensional space, this may create greater activity in stabilizing the muscle groups (9). On the other hand, machine exercises may be safer because the lifter need only provide unidirectional control of the resistance (2). In addition, machines may allow for greater overload to the primary muscles because of the reduced stabilizing requirement (13).

Although previous studies have compared similar machine and free weight exercises (1, 11, 13), the debate over differences in muscle utilization between the two modes is not supported by any direct investigations of muscle activity. Electromyography (EMG) reveals periods of electrical activity in a muscle (6). The EMG signal can be quantified by calculating the integral of the EMG pattern (IEMG) as the area under the linear envelope (20).

The purpose of this study was to calculate IEMG values during the ascent and descent phases of the bench press, and to compare the values between lifts performed with free weights versus those via a guided weight machine. The bench press was used because it is a multijoint exercise common to most strength training programs.

Methods

Five male strength trainers volunteered for the study and provided informed consent in accordance with university policy. Prior to testing, all subjects had been engaged in a strength training regimen of at least three sessions a week for the past year. To ensure familiarity with bench pressing technique, experienced lifters were used. All subjects regularly used the free weight bench press in their program and had practiced with the machine bench press (Universal) prior to data collection.

Data were collected in two phases. In Phase 1 the one repetition maximum (1-RM) for each subject was determined on both the free weight and machine bench press. In Phase 2, conducted 1 week later, muscle activity and joint position data were collected during bench press performance at 80% (high load) and 60% (low load) of the subject's 1-RM on both the free weight and machine conditions.

Each subject was oriented to the equipment and methodology before data collection and was asked to avoid any upper body lifting for 48 hrs before both test sessions. The order of testing for free weight and machine 1-RM was randomized across subjects. The 1-RM was determined using a protocol outlined by Lombardi (14), with 4 min rest provided between each repetition.

Surface electromyography (EMG) was used to monitor activity in five upper extremity muscles: triceps brachii, anterior deltoid, medial deltoid, pectoralis major, and biceps brachii. Bipolar surface electrodes (silver-silver chloride; recording diameter = 11 mm; distance between electrode centers = 1 cm) were applied to the belly of each muscle over the approximate motor point (18), longitudinally in the direction of the muscle fibers. At the sites of electrode attachment, the skin was shaved, lightly sanded with fine sandpaper, and washed with alcohol.

The EMG signals were differentially amplified 500 or 1,000 times (amplifier input impedance: 20 MΩ; common mode rejection ratio: 10,000:1). Amplifiers were set with a half-amplitude low-frequency cutoff of 3 Hz and a half-amplitude high-frequency cutoff of 1,000 Hz, each with a roll-off of –6dB per octave. Once in place, the electrodes remained secured to the skin during collection of EMG data from both the free weight and machine trials.

Twin axis, strain gauge electrogoniometers ("elgon", Penny & Giles, Model M-110, Santa Monica, CA) were secured over the shoulder and the elbow joints to record flexion/extension at the elbow joint and horizontal abduction/adduction at the shoulder joint. One elgon was placed on the lateral surface of the right elbow joint when the elbow was fully extended in accordance with the manufacturer's operating instructions. The second elgon was placed on the superior surface of the right shoulder while the arm was abducted, with the fixed endblock placed slightly lateral to the trapezius and the telescopic endblock on the upper arm. Endblocks were securely affixed to the subject using double-sided tape between the endblock and the skin, with a layer of single-sided adhesive tape applied over the endblock onto the skin to ensure a secure fixation. Alignment of both elgons over the joints was visually verified between each trial.

A spotter assisted the subject to full elbow extension on the machine lift, and stabilized the bar before and after the lift for all free weight conditions. Each subject used a standardized grip width for both modes of lifting. Subjects were not allowed to bounce the bar off the chest when lowered to nipple level during the free weight bench press, nor was the weight stack allowed to touch when performing the lift on the machine bench press.

Exercise mode performance order was counterbalanced across subjects. Each subject performed 20 trials during the testing session, 10 free weight and 10 machine. For both modes the subjects completed 5 trials at 80% of 1-RM (high load) followed by 5 trials at 60% of 1-RM (low load). They were provided 2 min rest between each trial and condition. A tape recorded command of 3.0 sec during the descent phase and 2.9 sec for the ascent phase was used to maintain a consistent cadence across trials.

The EMG and elgon signals were sampled at 500 Hz using an analog to digital board installed in the expansion box of a portable computer. The analog/digital sampling rate was limited to 500 Hz by the number of channels recorded and the length of the sampling period (5.5 s). Following each trial, data were plotted for qualitative assessment of the EMG data, then stored on hard disk for later processing.

The first step in data analysis was to identify from the elgon data of the elbow and shoulder the start, midpoint, and end of each trial. The start and end of the movement were defined, respectively, as a break from and a return to the resting position. Midpoint was identified as the point of maximum flexion of the elbow and maximal horizontal abduction of the shoulder. The descent phase was defined as the interval from the start to the midpoint of the movement, and the ascent phase was defined as the interval from the midpoint to the end of the movement.

EMG values in microvolts (μV) were calculated from the A/D units for each muscle during each trial. The EMG signal of each muscle was then full-wave rectified and low-pass filtered at 3 Hz using a fourth-order Butterworth filter to create a linear envelope (20). Using the start, midpoint, and endpoint identified from the elgon data of each trial, the integrals of the linear envelope in μV · s were calculated over the descent and ascent phases for each muscle during each trial. The five-trial mean value of the IEMG of each muscle for each phase of the lift was calculated for each subject. These mean values were then used in calculating the group mean value and standard deviation for each phase of each muscle.

The mean values were statistically analyzed using planned comparisons (12). Planned comparisons were used because the comparisons of high versus low load within mode, and machine versus free weight within load, were the only ones of interest. In view of the low number of subjects in the study, α was set at 0.1 for all comparisons to increase the power of the statistical analyses (7).

Results

To control lift speed, subjects were asked to perform the bench press with 51 and 49% of lift time for the descent and ascent phases, respectively. The four-condition mean and standard deviation values for the descent and ascent phases for each subject are presented in Table 1. Although the descent and ascent phases for each subject varied from the tape recorded cadence,

Table 1
Mean and *SD* of Total Lift Time for Both Phases of the Bench Press for Each Subject

	% Descent phase		% Ascent phase	
Subject	*M*	*SD*	*M*	*SD*
1	44.14	2.73	55.86	2.73
2	56.55	3.90	43.45	3.90
3	49.66	5.11	50.34	5.11
4	52.15	3.18	47.85	3.18
5	44.04	3.65	55.96	3.65
Mean	49.30	5.36	50.70	5.36

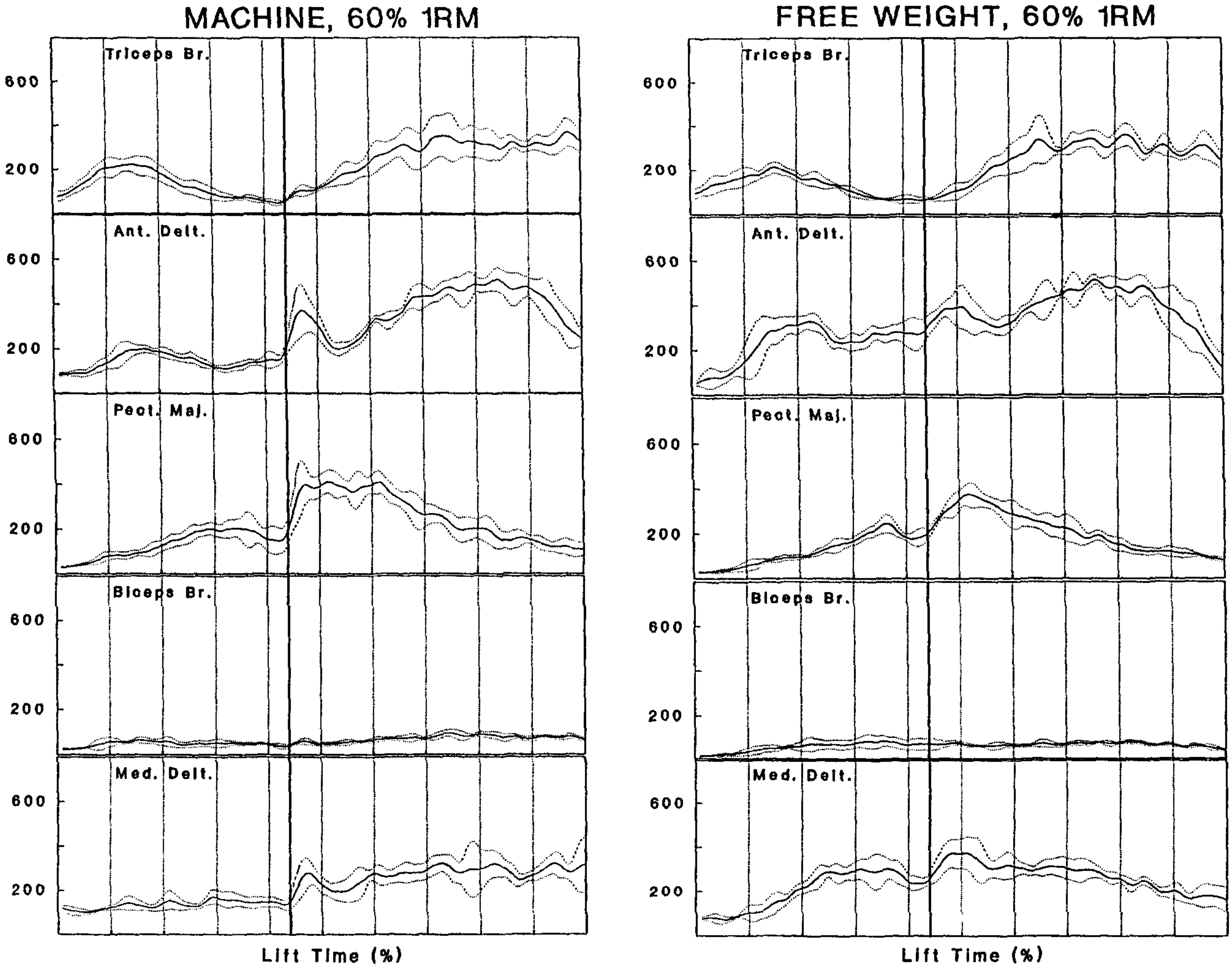

Figure 1. Linear envelopes (5 trials) of a representative subject at 60% of 1-RM on the machine and free weight bench press. Thick vertical line shows transition from lowering (descent) to pressing (ascent) of the bar. Units for vertical axis are μV.

each subject used a relatively consistent cadence across the four conditions (the average coefficient of variation across subjects and phases was 7.4%).

Figures 1 and 2 present a single subject's linear envelopes for the two modes of lifting at 60 and 80% of 1-RM, respectively. The greatest amount of muscle activity was evident during the ascent phase. The low load patterns were similar in temporal profile to the high load profiles, but lower in magnitude.

The group mean and standard deviation values for IEMG during the high and low loads within the same mode are presented in Table 2. The IEMG mean value was always greater for the high load compared to the low load. The difference was statistically significant for 6 of 10 comparisons (5 muscles × 2 phases) for free weight lifts, and 7 of 10 comparisons for machine lifts.

The results of the planned comparisons conducted between the free weight and machine IEMG mean values are also presented in Table 2 and summarized in Table 3. The anterior and medial deltoids were the only muscles exhibiting consistently higher IEMG mean values in one mode across both loads and phases. For both muscles, the mean IEMG value was greater for free weight than for machine lifting, and the difference was statistically significant at the low load. The IEMG mean values for both the triceps brachii and the pectoralis major were greater for free weight than machine lifting for three of the four mode/phase conditions, but no difference was statistically significant. The IEMG mean values for the biceps brachii were higher for machine lifts during the descent phase, but higher for free weight lifts during ascent. Neither difference was statistically significant.

Discussion

The usefulness of IEMG to compare muscle activity between different modes of exercise is dependant on the ability to detect differences in IEMG values between loads known to be physiologically different. An 80% load is frequently used in strength training programs, as it is more effective for building strength than

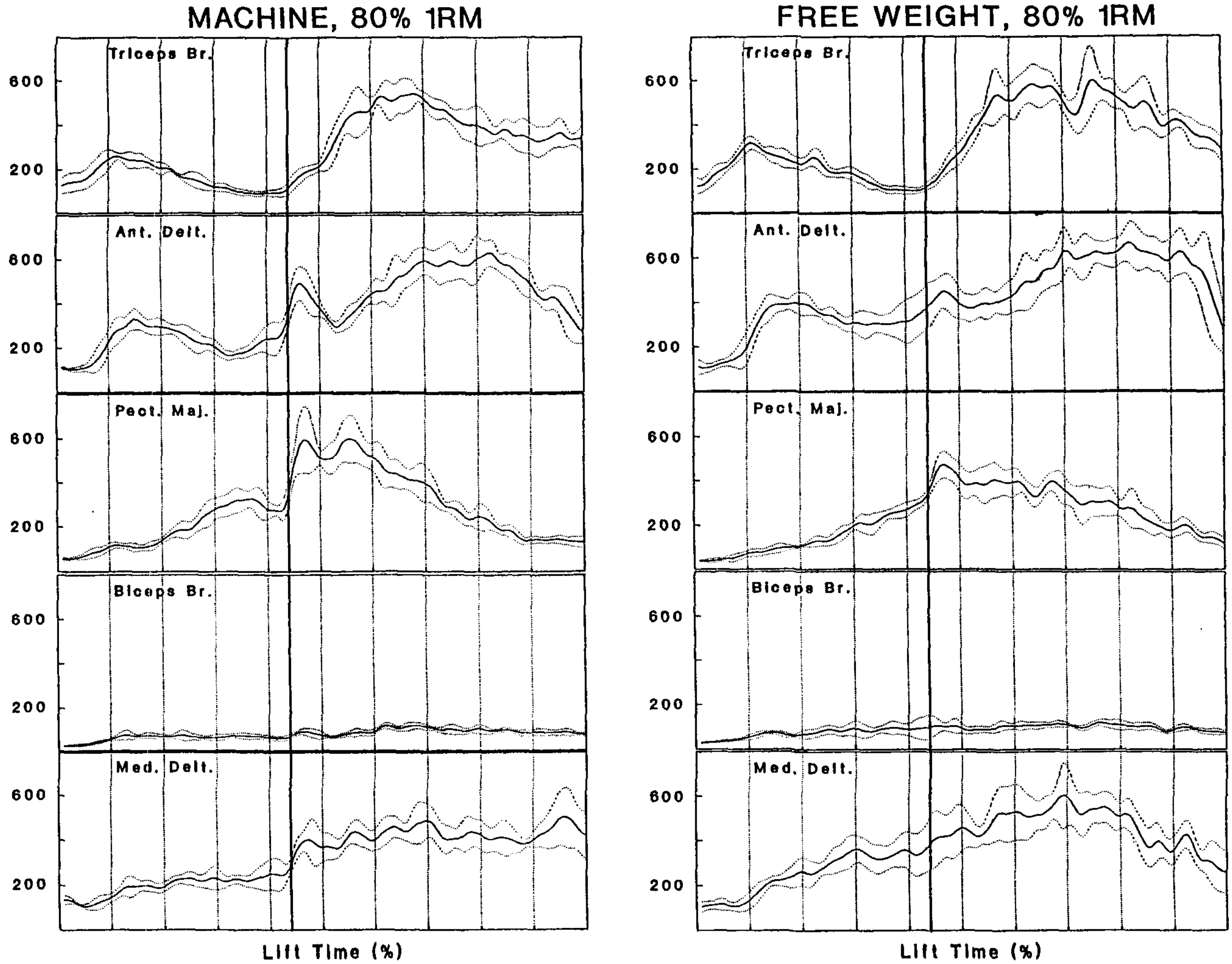

Figure 2. Linear envelopes (5 trials) of a representative subject at 80% of 1-RM on the machine and free weight bench press. Thick vertical line shows transition from lowering to pressing of the bar. Units for vertical axis are µV.

light loads are (3, 19). The 80% load creates a muscular overload yet does not cause extreme fatigue when completing 5 reps. A 60% load is considered light and was used because it activates fewer motor units (16). Physiologically, differences in muscle activity level (recruitment and/or rate coding) would be expected between the two loads. Planned comparisons identified differences in IEMG values between the low and high loads within the same mode. The high percentage of significant differences identified in IEMG values between high and low loads within the same mode of exercise suggests that the procedures used were capable of identifying differences in muscle activity.

The design of a bench press machine causes the bar to follow the same path during both the ascent and descent phases, while the bar path during the free weight bench press can vary across the ascent and descent phases (5, 15, 19). Lander et al. (13) suggested that the lifter must devote force to balance and stabilize the bar in two horizontal directions during a free weight bench press. Strength training advocates (8, 10) assume that balancing and stabilizing the bar during free weight lifts requires greater muscle activity than do machine lifts.

The results of this study support the hypothesis that greater muscle activity is present during free weight training than during machine lifting. The IEMG was higher during free weight lifting for 16 of the 20 mode/phase comparisons, with the difference most evident at the 60% 1-RM load where four differences in IEMG were statistically significant.

The observed difference in muscle activity between the two modes was greatest for the deltoid muscles during low load lifting. The IEMG of the anterior and the medial deltoids were 50 and 33% higher, respectively, during the free weight compared to the machine lifts. Since the anterior deltoid tends to resist lateral rotation of the humerus, and the medial deltoid tends to resist adduction of the humerus, the increased activity in these muscles may reflect their contribution to stabilizing the shoulder as well as pressing the weight bar. Scheving and Pauly (17) reported that the three heads of the deltoid are active in all movements of the arm, with one head acting as a prime mover

Table 2
IEMG Mean Values (*SD*) During the Free Weight and Machine Bench Press at Different Loads (n = 5; units μV · s)

		60 %		80%		Comparison			
Muscle	Phase	Free wt	Mach.	Free wt.	Mach.	M_l	M_h	L_f	L_m
Triceps	Des.	0.4254	0.3590	0.4602	0.5114				
brachii		(0.4609)	(0.3215)	(0.2900)	(0.5538)				
Triceps	Asc.	0.6829	0.5849	1.1235	1.1064			*	*
brachii		(0.5531)	(0.4089)	(0.7051)	(0.7688)				
Anterior	Des.	0.9009	0.5983	1.0418	0.9599	*			*
deltoid		(0.4775)	(0.2187)	(0.4446)	(0.3879)				
Anterior	Asc.	1.3989	0.9388	1.6948	1.6177	*			*
deltoid		(0.6773)	(0.2795)	(0.7060)	(0.6929)				
Pectoralis	Des.	0.2867	0.2944	0.4374	0.4227			*	*
major		(0.1366)	(0.1377)	(0.3036)	(0.1964)				
Pectoralis	Asc.	0.5425	0.5207	0.8840	0.8480			*	*
major		(0.4129)	(0.3311)	(0.7090)	(0.5616)				
Biceps	Des.	0.0842	0.1004	0.1072	0.1377		*	*	
brachii		(0.0385)	(0.0921)	(0.0394)	(0.0808)				
Biceps	Asc.	0.0964	0.0918	0.1488	0.1358			*	*
brachii		(0.0327)	(0.0349)	(0.0524)	(0.0408)				
Medial	Des.	0.3649	0.2623	0.4253	0.3910	*			
deltoid		(0.2720)	(0.1920)	(0.3009)	(0.3157)				
Medial	Asc.	0.5603	0.4376	0.7653	0.7248	*		*	*
deltoid		(0.2765)	(0.2477)	(0.2979)	(0.3285)				

M_l: Mode low (FW 60% vs. mach. 60%); M_h: Mode high (FW 80% vs. mach. 80%); L_f: Load free weight (FW 80% vs. FW 60%); L_m: Load machine (mach. 80% vs. mach. 60%). $*p \leq 0.1$

Table 3
Summary of Planned Comparison for Free Weight Versus Machine Group Analysis

		60% of 1 RM		80% of 1 RM	
Muscle	Phase	Free wt.	Mach.	Free wt.	Mach.
Triceps	Descent	+			+
brachii	Ascent	+		+	
Anterior	Descent	*		+	
deltoid	Ascent	*		+	
Pectoralis	Descent		+	+	
major	Ascent	+		+	
Biceps	Descent		+		*
brachii	Ascent	+		+	
Medial	Descent	*		+	
deltoid	Ascent	*		+	

+Greater IEMG for this mode, n.s.
*Greater IEMG for this mode, $p \leq 0.1$.

and the other heads active to stabilize the humerus in the glenoid cavity.

The smaller difference between modes in IEMG activity of the deltoids at the 80% 1-RM load might be attributed to increased joint stiffness from the increased activity in all muscle groups around the shoulder, eliminating the need for the anterior and medial deltoids to work against external rotation and adduction of the humerus.

The existence of notable individual variability in muscle activity from the group mean data must be acknowledged. For example, although the difference was not statistically significant, the group mean data shown in Table 2 indicate greater activity of the pectoralis major during the ascent phase of free weight lifts compared to machine lifts with both low and high loads. However, Figure 1 clearly indicates greater activity in the pectoralis major during the ascent phase with the machine lift. Whether the individual differences reflect typical biological variability or joint and muscle mechanics specific to an individual is beyond the scope of the present study. However, studies designed to explain the presence of individual differences represent a viable direction for research investigating muscle activity during weight training exercises.

Only experienced lifters were used in the study. It is possible that greater differences between the two modes of bench press would be exhibited by novice lifters. Experienced lifters may have developed an efficient technique to control the free weight bar, reducing the muscle activity in the stabilizing muscles.

The results of this study comparing IEMG values suggest the following: (a) there is a tendency for greater muscle activity when performing the bench press with free weights; (b) differences between bench press modes are greater at 60% than at 80% of 1-RM; (c) there are individual differences in muscle activity patterns when performing the bench press with free weights versus a machine.

Practical Application

Higher IEMG values for the anterior and medial deltoid muscles suggest that shoulder stabilizing muscles are more active during the bench press performed using free weights compared to a machine. Individual variability in the IEMG values for the pectoralis major and triceps brachii suggest that factors other than training mode, possibly including joint and muscle mechanics specific to an individual, determine which mode of training invokes greater muscle activity during a bench press.

References

1. Andrews, J.G., J.G. Hay, and C.L. Vaughan. Knee shear forces during squat exercise using a barbell and a weight machine. In: *Biomechanics VIII-B*. H. Matsui and K. Kabashi, eds. Champaign, IL: Human Kinetics, 1983. pp. 923-927.
2. Ariel, G.B. Resistive training. *Clin. Sports Med.* 2(1):55-69. 1983.
3. Berger, R.A. Effect of varied weight training programs on strength. *Res. Quar.* 36:141-146. 1965.
4. Coleman, A.E. Nautilus vs universal gym strength training in adult males. *Am. Corr. Ther. J.* 103-107. July-Aug. 1977.
5. Elliott, B.C., G.J. Wilson, and G.K. Kerr. A biomechanical analysis of the sticking region in the bench press. *Med. Sci. Sports Exerc.* 21:450-461. 1989.
6. Enoka, R.M. *Neuromechanical Basis of Kinesiology*. Champaign, IL: Human Kinetics, 1988.
7. Franks, B.D., and S.W. Huck. Why does everyone use the .05 significance level? *Res. Quar. Exerc. Sport* 57:245-249. 1986.
8. Garhammer, J. *Sports Illustrated Strength Training*. New York: Winner's Circle Books, 1984.
9. Garhammer, J. Weight lifting and training. In: *Biomechanics of Sport*. C.L. Vaughn, ed. Boca Raton, FL: CRC Press, 1989, pp. 169-211.
10. Hatfield, F.C. *Bodybuilding: A Scientific Approach*. Chicago: Contemporary Books, 1984.
11. Hay, J.G., J.G. Andrews, C.L. Vaughan, and K. Ueya. Load, speed and equipment effects in strength-training exercises. In: *Biomechanics VIII-B*. H. Matsui and K. Kabashi, eds. Champaign, IL: Human Kinetics, 1983. pp. 939-950.
12. Keppel, G. *Design and Analysis: A Researcher's Handbook*. Englewood Cliffs, NJ: Prentice Hall, 1982.
13. Lander, J.E., B.T. Bates, J.A. Sawhill, and J. Hamill. A comparison between free-weight and isokinetic bench pressing. *Med. Sci. Sports Exerc.* 17:344-353. 1985.
14. Lombardi, V.P. *Beginning Weight Training*. Dubuque, IA: Brown, 1989.
15. Madsen, N., and T. McLaughlin. Kinematic factors influencing performance and injury risk in the bench press exercise. *Med. Sci. Sports Exerc.* 16:376-381. 1984.
16. McDonagh, M.J., and C.T. Davies. Adaptive responses of mammalian skeletal muscle to exercise with high loads. *Eur. J. Appl. Physiol.* 52:139-155. 1984.
17. Scheving, L.E., and J.E. Pauly. An electromyographic study of some muscles acting on the upper extremity of man. *Anat. Rec.* 135:239-246. 1959.
18. Warfel, J.H. *The Extremities: Muscles and Motor Points*. Philadelphia: Lea & Febiger, 1985.
19. Wilson, G.J., B.C. Elliott, and G.K. Kerr. Bar path and force profile characteristics for maximal and submaximal loads in the bench press. *Int. J. Sport Biomech.* 5:390-402. 1989.
20. Winter, D.A. *Biomechanics and Motor Control of Human Movement*. New York: Wiley-Interscience. 1990.