

Muscle Use During Isometric Co-contraction of Agonist-Antagonist Muscle Pairs in the Upper and Lower Body Compared to Abdominal Crunches and a Commercial Multi Gym Exerciser

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ABSTRACT

Isometric exercise can be used for strength training. Generally, strength training requires heavy weights to be lifted on large pieces of gym equipment. However, the use of co-contraction of agonist and antagonist muscle pairs while the subject is standing has been suggested as a means of isometric strength training.

In the present investigation, the muscle activity, as assessed by the electromyogram, was examined in 6 male and 11 female subjects aged 22 to 28 years old to compare isometric exercise

induced by co-contraction of muscles in 3 areas of the body to the muscle use with exercise on commercial weight lifting equipment. The areas of the body undergoing isometric exercise were the arm, trunk, and leg muscles. Subjects exercised these areas for 25 seconds compared to 3 loads on a commercial TuffStuff Apollo 5900 gym system (TuffStuff Inc, Pomona, CA). The results of the experiments showed that isometric co-contraction of muscle while the subjects were standing still resulted in 5 times greater work than exercise on a commercial exercise gym for the muscle groups. Thus isometric exercise against agonist and antagonist pairs provides a good exercise regime.

INTRODUCTION

It is well established that isometric and isokinetic strength training increases muscle strength more than does dynamic exercise training.¹ By using isometric strength training with the joints at varying angles, even though the person is motionless during each exercise, specific muscles can be trained through the range of motion.¹ This type of isometric strength training can be useful in a variety of clinical situations such as aiding in the repair of shoulder damage caused by injuries.²

Strength training is specific to the muscle being exercised³ as is the angle of the joint during training.⁴ If isometric exercise is accomplished at a fixed joint angle, strength increases little at other joint angles. By exercising muscles isometrically at various angles, this phenomenon can be overcome and strength can be increased at all joint angles.⁴ While some of the increase in muscle performance and strength previously has been linked to motor skill training associated with isometric exercise,⁵ more recent studies show that muscle strength training does increase actin and myosin synthesis,⁶ and increases muscle enzymes such as lactic acid dehydrogenase and creatinine phosphokinase.¹

While isometric strength decreases with age⁷ and increases with body fat due to the additional load of lifting greater body weight,⁸ strength training retards much of the aging loss.³ Even when endurance varies during the menstrual cycle, isometric strength is constant.⁹

Isometric strength training is somewhat specific. Only sustained isometric contractions cause an increase in isometric endurance and isometric strength together.¹⁰ Dynamic exercise does not have this effect.¹ Some people feel that the rapid increase in strength due to isometric training is just a change in the elastic properties of muscle. But numer-

ous studies show that there is no change in the elastic property of muscles with isometric training¹¹ and the increase in strength and motor performance is incontrovertibly due to a synthesis of actin and myosin in muscle.¹²

Given the above, when muscle strength is weak, as is commonly seen with bed rest,¹³ spinal cord injury, stroke, or even athletic injuries, isometric exercise has been recommended as a strength training modality.^{14,15} It has been used with the geriatric population to increase strength.^{14,15} It is also used during spaceflight where access to large pieces of exercise equipment is not practical.^{16,17} Isometric training is often accomplished in people who have had a spinal cord injury or stroke by using electrical stimulation to elicit muscle contractions.¹⁸ Electrical stimulation is also used for isometric training in non-paralyzed subjects.¹⁹

Specific strength training protocols have great benefits for sports injuries as well.²⁰ Strength training is beneficial for preventing back injury and removing lower back pain.²¹⁻²³ Even in children, increased muscle strength is correlated to a decreased incidence of back pain.²⁴ There seems to be no difference in the ability to train strength in younger and older women²⁵ and men, therefore isometric exercise has a beneficial effect on all populations.

Thus, there seems to be a general agreement in the literature that isometric strength training develops strength fast and is beneficial for both preventing and treating many types of therapeutic injuries. However, most strength training regimes involving isometric exercise use either free weights or large pieces of equipment such as a roman chair.²⁶ Many other studies use large commercial gyms such as Cybex exercise trainers (Cybex International, Inc; Medway, MA)^{14,27} or other complex pieces of exercise equipment.¹⁷ Most people are

Table 1. General Characteristics of the Subjects

	Age (years)	Height (cm)	Weight (kg)
Mean \pm standard deviation	24.8 \pm 1.9	182.8 \pm 65.2	73.2 \pm 16.4

either reluctant to join a gym or do not have access to such equipment.

However, in other studies unrelated to strength training, it was found that co-activation of agonist-antagonist muscle pairs, such as the ankle musculature, occurs naturally during maximal isokinetic dorsiflexion.²⁸ Agonist-antagonist co-contraction is also seen and correlated to strength in stroke patients.²⁹ This same phenomenon of co-activation is also seen for the vastus lateralis muscle in pubertal children and adults.³⁰ Thus activation of agonist and antagonist pairs is normally found in children and adults. For those with a disability, activation of the two muscle groups simultaneously helps maintain strength.³¹ In some studies positive results have been seen when electrical stimulation of antagonist muscle has been used with voluntary agonist contraction to strength train.^{32,33}

Therefore, rather than using complex exercise equipment, activation of agonist and antagonist pairs simultaneously seems to be a way of generating an isometric contraction. At the same time, this activation of muscle pairs would be quite useful for strength training. The purpose of the present investigation was to compare muscle use during isometric co-contraction of three different muscle groups in the body and compare these to the muscle activity during weight lifting with commercial exercise equipment and abdominal crunches.

MATERIALS AND METHODS

Subjects

The subjects in this study were 6 males and 11 females in the age range of 22 to 28 years old. The sample size was suffi-

cient to achieve statistical significance by power analysis. Medical screening was conducted prior to participation to assure subjects were free of cardiovascular, neurological, or orthopedic injuries. The general characteristics of the subjects are listed in Table 1. All protocols and procedures were approved by the Institutional Review Board of Azusa Pacific University and all subjects signed a statement of informed consent.

Methods

Isometric Exercise – Isometric exercise was accomplished in 3 areas of the body. Subjects were told to simultaneously contract agonist and antagonist pairs of muscles for 25 seconds and then rest for 2 minutes. The exercise included;

Set 1 - Contracting the biceps and triceps groups together with the elbows and 90° and arms forward as shown in Figure 1.

Set 2 - Contracting the biceps and triceps groups together with the elbows at 90° at the elbow and the shoulder extended by 90° as shown in Figure 2.

Set 3 - Contracting the quadriceps and hamstring groups and gluteus maximus and medius muscles with the knee bent at 5°, the person erect but leaning forward about 15° as shown in Figure 3.

In addition, 10 subjects completed 2 subsets of exercise in the set 1 and 2 experiments. For these exercises, the subjects repeated the exercise as described above but were told to concentrate on using abdominal (rectus abdominus) and back extensor muscles.

Determination of muscle activity – To determine muscle activity, the electromyogram (EMG) was used. EMG



Figure 1. A subject using co-contraction of the biceps-triceps muscle groups.



Figure 2. A subject using co-contraction of the biceps-triceps but with the elbows at 90 degrees.



Figure 3. A subject using co-contraction of hamstrings-quadriceps groups.

was recorded by two electrodes and a ground electrode placed above the active muscle.³⁴⁻³⁹ The relation between tension in muscle and surface EMG amplitude is linear.^{35,40} Thus, the amplitude of the surface electromyogram can be used effectively as a measure of activity of the underlying muscle by simply normalizing the EMG in terms of a maximal effort. Muscle activity was assessed by first measuring the maximum EMG of the muscle during a maximal effort and then, during any exercise, assessing the percent of maximum EMG to calculate the percent of muscle activity.³⁵⁻³⁷ The electrical output from the muscle was amplified with a biopotential amplifier (EMG 100C amplifier, Biopac Inc., Goletta, CA) with a gain of 2000 and frequency response, which was flat from DC to 1000 Hz. The amplified EMG was digitized with a 16-bit analog to digital converter (MP150, Biopac Inc.) and sampled at a frequency of 500



Figure 4. A subject exercising on the commercial weight lifting equipment

samples/sec. The software to analyze the EMG was the Acknowledge 3.8.1 package (Biopac Inc., Goletta, CA).

Commercial Weight Lifting Equipment –

A TuffStuff Apollo 5900 gym system (TuffStuff Inc, Pomona, CA) was used for these studies. The exercises used were the chest press, biceps curl, triceps curl, lat pull down, abdominal extension, abdominal flexion, leg extension, leg curl, and leg press (Figure 4).

Abdominal floor crunches – This exercise was done supine, with the feet on the floor, heels 12-18 inches apart, and the knees flexed. The abdominals were flexed to lift the shoulders and head off the floor to an angle of 30 degrees. The arms were crossed on the chest.

Procedures

Three series of exercises were performed. Prior to any measurements, a maximal isometric contraction was exerted to measure the maximum EMG

during a 100% effort. This was used to normalize EMG muscle activity during exercise to assess the use of the muscles.

Series 1 – During a 25-second isometric co-contractions of the appropriate muscle groups, EMG activity was measured. Three separate sets of isometric contractions were conducted as described under methods for 25 seconds and repeated 4 times. Also as described under methods, two subsets of isometric contractions was performed in the upper body exercises to increase abdominal muscle use. EMG for upper body exercise was measured in the biceps, triceps, deltoid, pectoralis major, rectus abdominus, lumbar muscles, and latisimus dorsi muscles. For lower body exercise, the muscles examined were the quadriceps, hamstring, gastrocnemius, gluteus maximus, rectus abdominus, and lumbar muscles.

Series 2 – This series involved abdominal floor crunches. EMG was measured as described above.

Series 3 – Lastly, subjects used commercial weightlifting equipment and contracted each individual muscle group against 3 different loads as shown in Table 2. EMG was measured during these contractions. Subjects were asked to exercise at a normal rate for weight lifting for a period of at least 30 seconds and, from these data, a 25-second average of muscle use was computed.

Data Analysis

Data analysis included the calculation of means, standard deviations and *t*-tests as well as analysis of variance (ANOVA). The level of significance was $P < 0.05$.

RESULTS

Series 1, Isometric Exercise

When the arms were in the forward position (Figure 1), isometric exercise was used to contract agonist-antagonist pairs in the upper body. The EMG activity was high throughout the entire 25-

Table 2. Exercise and Workloads

Exercise	Trial 1	Trial 2	Trial 3
	Weight	Weight	Weight
Chest Press	20 lbs, 9.072 kg	40 lbs, 18.143 kg	60 lbs, 27.215 kg
Biceps Curl	20 lbs, 9.072 kg	30 lbs, 13.608 kg	40 lbs, 18.143 kg
Triceps Curl	20 lbs, 9.072 kg	30 lbs, 13.608 kg	40 lbs, 18.143 kg
Lat Pull Down	20 lbs, 9.072 kg	30 lbs, 13.608 kg	40 lbs, 18.143 kg
Abdominal Extension	20 lbs, 9.072 kg	40 lbs, 18.143 kg	60 lbs, 27.215 kg
Abdominal Flexion	20 lbs, 9.072 kg	40 lbs, 18.143 kg	60 lbs, 27.215 kg
Leg Extension	20 lbs, 9.072 kg	40 lbs, 18.143 kg	60 lbs, 27.215 kg
Leg Curl	20 lbs, 9.072 kg	40 lbs, 18.143 kg	60 lbs, 27.215 kg
Leg Press	60 lbs, 27.215 kg	120 lbs, 54.431 kg	180 lbs, 81.647 kg

second period. The muscle use, as assessed by the EMG is shown for a typical subject in Figure 5. During the 25-second period that the contraction was maintained, EMG activity was continuous. As shown in Figure 6, even at the beginning of the 25-second period, muscle activity was close to 80% for the biceps and triceps muscle as well as the pectoralis major muscles. While muscle activity was low for the rectus abdominus, the deltoids had considerable muscle activity as did the back extensors and latissimus dorsi. Further, during the 25-second period, there was a small but progressive and significant ($P < 0.01$, ANOVA) increase in muscle activity in the biceps, triceps, and pectoralis major muscles, as well as the deltoid muscles showing muscle fatigue. For example, for the biceps muscle, the average for the subjects was $78.6 \pm 14.2\%$ muscle activity for the biceps at the onset of the 25-second period. After 15 seconds, EMG activity increased to $95.8 \pm 14.2\%$ and after 25 seconds, muscle activity had increased to $97.6 \pm 14.3\%$ of muscle activity for the biceps.

While the muscle activity on muscles like the rectus abdominus were low averaging only about 20% of muscle activity, there was still significant muscle activity sustained over the 25-second

period. Muscle activity for the back extensors, which average $52.2 \pm 19.4\%$, was significantly higher than the rectus abdominus muscles ($P < 0.01$) for the subjects examined here. This amounted to half the muscle activity of the back extensors showing significant muscle activity.

As shown in the bottom of Figure 6, by multiplying the percent muscle activity by the duration of the contraction, the work index can be determined. The work was found to be was 2266 for the biceps, 2382 for the triceps, 2120 for the pectoralis major muscles, and for the deltoid 2122 units. Muscle activity was less for the rectus abdominus averaging a total work of 472.1. For the back extensors and latissimus dorsi the average was approximately 1200 work units. Thus, for the average of all muscles as shown in Figure 6 by the bar on the right hand side of the Figure, the average work was 1792 units.

In the second isometric exercise (set 2), with the arms facing posterior (Figure 2, triceps workout), muscle use was also high as shown in Figure 7. With the arms placed toward the posterior of the body, muscle use was highest for the deltoid muscles. As was shown in Figure 6, muscle activity increased continuously over the 25-second period showing mus-

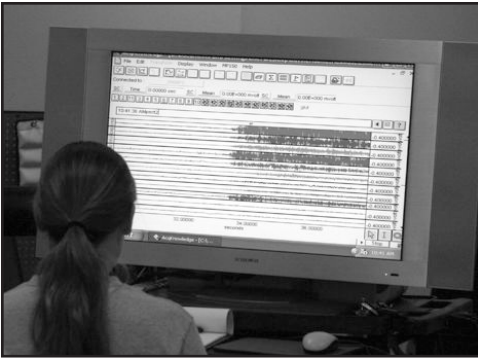


Figure 5. The EMG during upper body isometric contraction-co-contraction of muscle

cle fatigue for all muscles examined. However, the deltoid muscle use here was significantly higher than in the set 1 experiment ($P < 0.01$). In addition, triceps activity was near maximal throughout the entire exercise.

One difference in this exercise was that the biceps activity was significantly lower than the previous series 1 experiment ($P < 0.05$). As shown as Figure 7, rectus abdominus activity was still low but was not significantly different than in the previous set 1 experiments ($P > 0.05$). Back extensor activity was significantly higher in this series averaging 75% of muscle activity over the 25-second period in the data shown in Figure 6 ($P < 0.01$). Latissimus dorsi activity was also higher. In this series of experiments, the latissimus dorsi activity was nearly maximal throughout the entire 25-second period whereas in the first series of experiments it was on the average using 50% of muscle activity. This difference was significant ($P < 0.01$). Looking at the bottom of Figure 7, muscle work averaged 2401 work units and the greatest work done was for the latissimus dorsi, back extensors, and triceps muscles in this series.

When the protocol was modified in 10 subjects to increase the abdominal muscle activity in the 2 upper body exercise protocols (series 1a and 2a), the results are shown in Figures 8 and 9.

Figure 8 illustrates the first upper body isometric series and Figure 9 the second series. During the first isometric series, when subjects concentrated on additional abdominal use, rectus abdominal activity increased to an average of 55% maximum muscle activity. Back extensors increased to 76% muscle activity. This increased muscle work to 1370 and 1900 units, respectively. The increase in abdominal flexor and extensor activity was significant ($P < 0.01$). In the second modified set, a similar increase was seen both in muscle use and total work. Here work was significantly higher for the back extensor and rectus abdominus muscles as shown in Figure 9. Other muscle groups did not statistically change when comparing series 1 to 2.

Isometric exercise was accomplished in the lower body by contracting the muscles while leaning forward as was shown in Figure 3. A typical EMG is shown in Figure 10. Muscle use is shown in Figure 11 in the upper panel and work in the lower panel. When lower body exercise was accomplished, the greatest muscle activity was in the quadriceps muscle. Muscle activity averaged $93.2 \pm 16.7\%$ at the beginning of the 15-second period and increased to $98.5 \pm 26.3\%$ at the end of the 15-second period in the quadriceps. Muscle activity for the rectus abdominus was lowest averaging at 17.3% of total muscle activity. Rectus abdominus activity in all three series (1, 2, and 3) of experiments was not significantly different from each other (ANOVA, $P > 0.05$) except as described for series 1 and 2a. When series 1 and 2 were repeated with conscious core muscle use, there was a significant increase in rectus abdominus muscle activity. Gastrocnemius activity was also high averaging 85% of muscle activity over the 25-second period. Back extensor muscle activity was low averaging only 30% of muscle activity. When examining the work in the lower panel

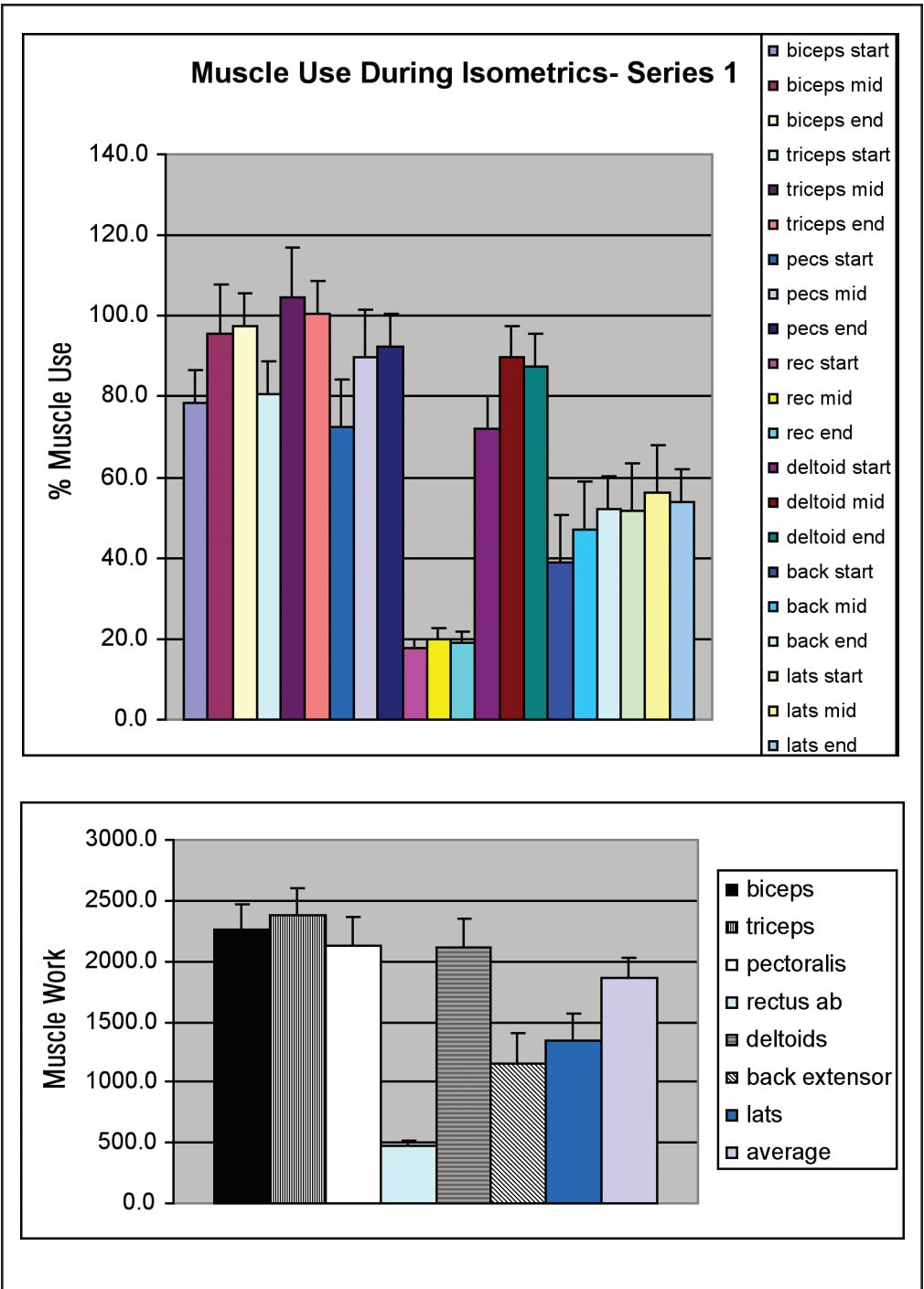


Figure 6. This graph shows the muscle use of the biceps, triceps, pectoralis major, rectus abdominus, deltoid, back extensors, and latissimus dorsi at the start, halfway through, and at the end of 25 seconds of a sustained isometric co-contraction of the upper body for the series 1 experiment described under methods. While the actual muscle use is shown in the bar graph in the upper panel, the muscle work (present muscle use times the duration in seconds) as an average over the 25-second period is shown in the lower panel. Each point is shown with the standard deviation.

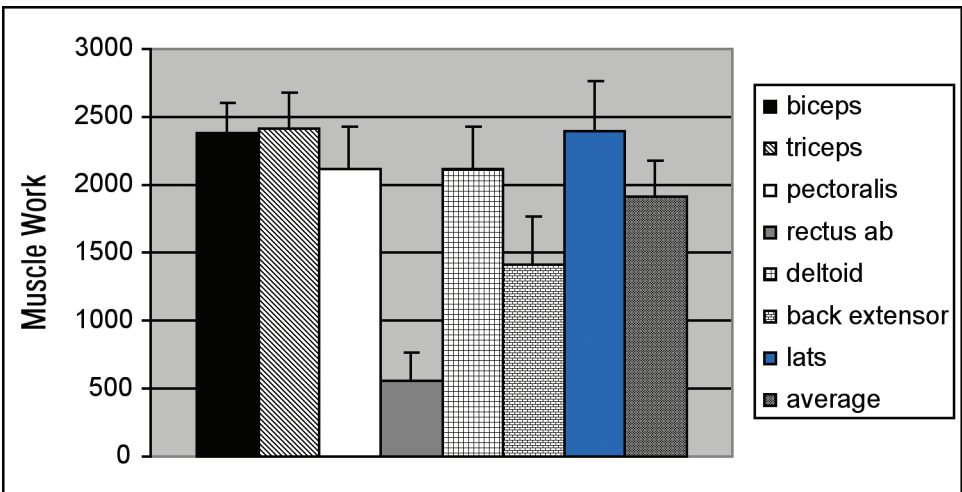
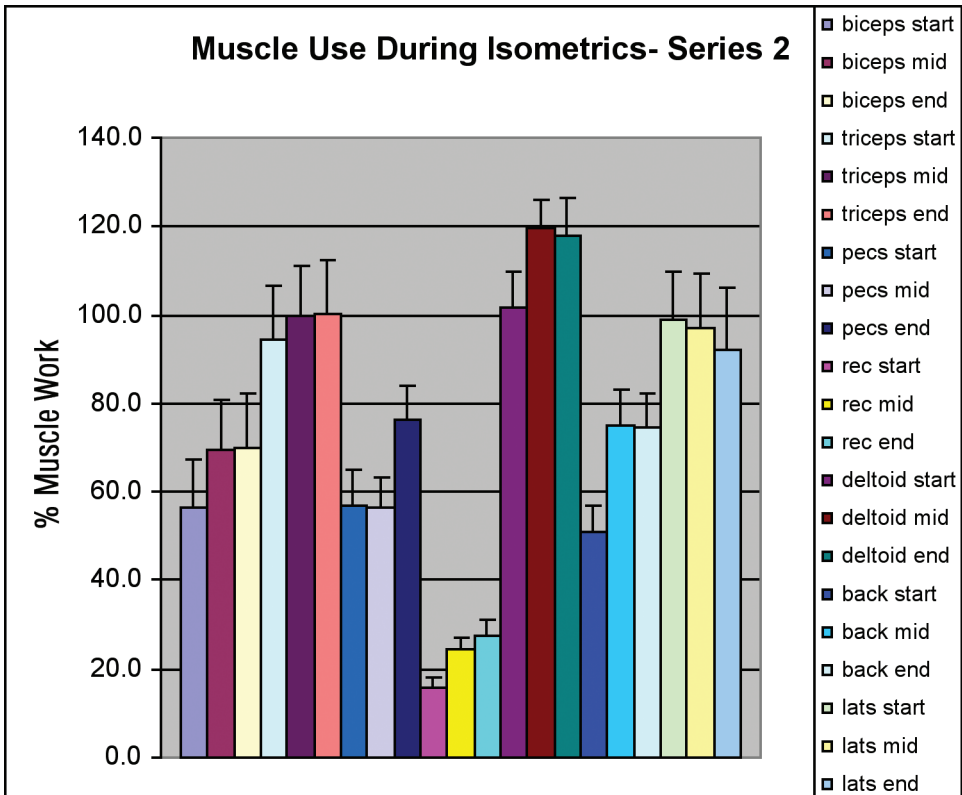


Figure 7. This graph shows the muscle use of the biceps, triceps, pectoralis major, rectus abdominus, deltoid, back extensors, and latissimus dorsi at the start, halfway through, and at the end of 25 seconds of a sustained isometric co-contraction of the upper body for the series 2 experiment described under methods. While the actual muscle use is shown in the bar graph in the upper panel, the muscle work (present muscle use times the duration in seconds) as an average over the 25-second period is shown in the lower panel. Each point is shown with the standard deviation.

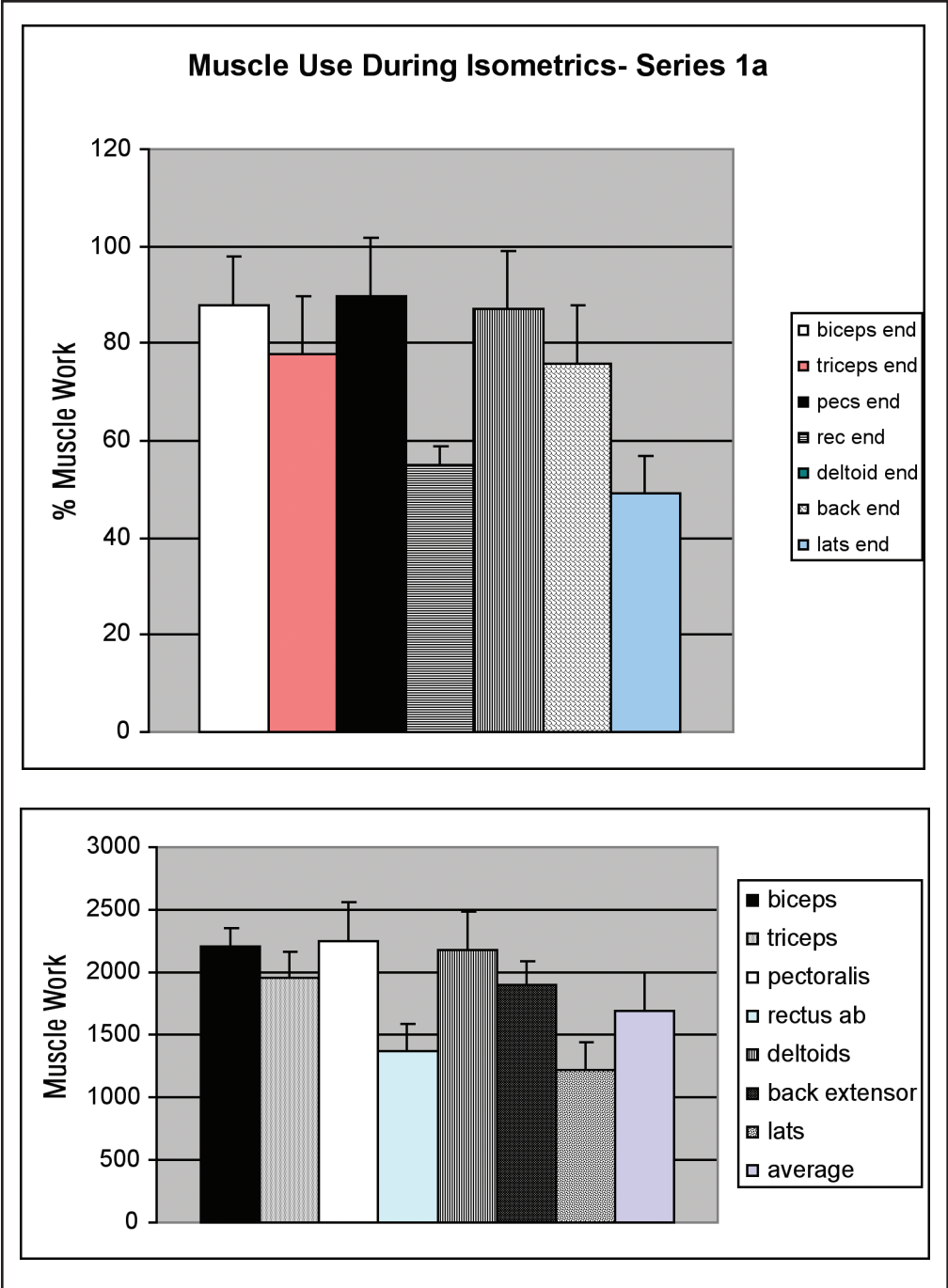


Figure 8. This graph shows the muscle use of the biceps, triceps, pectoralis major, rectus abdominus, deltoid, back extensors, and latissimus dorsi at the end of 25 seconds of a sustained isometric co-contraction of the upper body for the series 1 experiment described under methods when abdominal use was increased by a different protocol. While the actual muscle use is shown in the bar graph in the upper panel, the muscle work (present muscle use times the duration in seconds) as an average over the 25-second period is shown in the lower panel. Each point is shown with the standard deviation.

Muscle Use During Isometrics- Series 2a

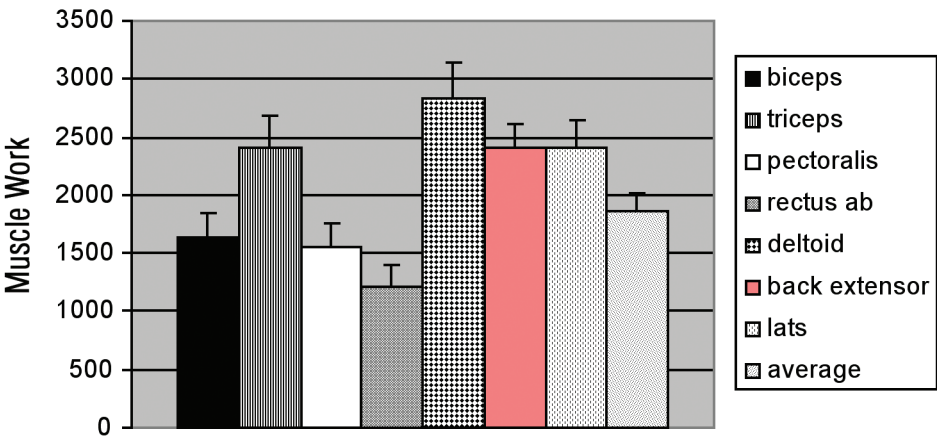
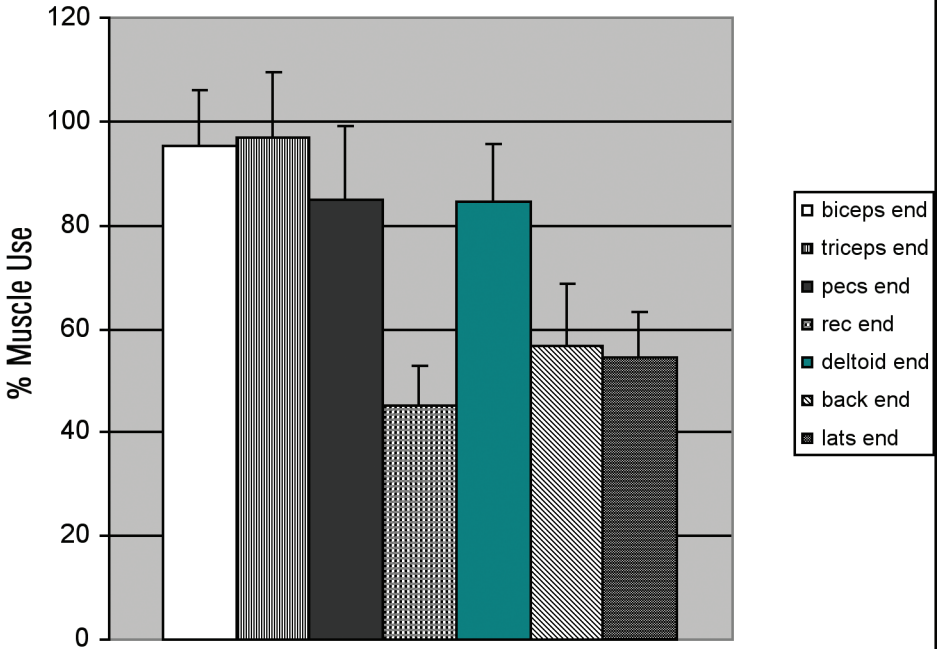


Figure 9. This graph shows the muscle use of the biceps, triceps, pectoralis major, rectus abdominus, deltoid, back extensors, and latissimus dorsi at the end of 25 seconds of a sustained isometric co-contraction of the upper body for the series 2 experiment described under methods with a protocol to increase abdominal muscle use. While the actual muscle use is shown in the bar graph in the upper panel, the muscle work (present muscle use times the duration in seconds) as an average over the 25-second period is shown in the lower panel. Each point is shown with the standard deviation.

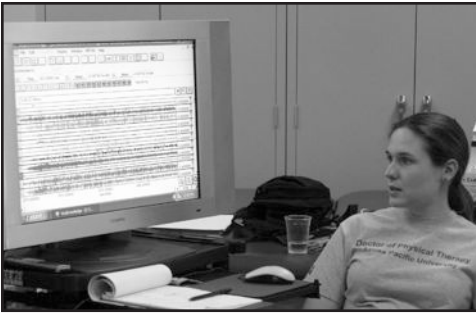


Figure 10. The EMG during co-contraction of the lower body muscles.

of Figure 11, total work here was significantly less than the other two series of experiments, averaging 1266 work units ($P < 0.01$). The greatest work was accomplished for the quadriceps at 1996 work units followed by the gastrocnemius at 872 work units. For the hamstring, work was also high at 1660 work units. The muscles with the lowest activity were the rectus abdominus muscles followed by the back extensors.

Series 2 - Abdominal crunches

Figure 12 shows the abdominal crunch results. Here the majority of the muscle use was seen in the abdominal muscles. Total work was 233.8 units for this exercise and muscle use was 28.7% of the muscle activity. The duration of each crunch from the start of one to the start of the other was 2.1 ± 0.4 seconds.

Series 3- Commercial Weight Lifting Equipment

Exercising on the commercial weight lifting equipment resulted in muscle use that was more specific than which was seen for the isometric exercise. Muscle work in the chest press is shown in Figure 13. The average muscle work during the chest press for the lowest work load averaged 117.6 units of work. The greatest activity was for the triceps, pectoralis major and the latissimus dorsi muscles. Even with these muscle groups, total work only averaged about 176.8

units. This was due to the fact that most muscle activity was during 1-second windows during the concentric phase of the exercise with little work at the onset and eccentric phase of each lift. Subjects here lifted continuously at a natural rate selected by the subject. Total work here and below was calculated over a 25-second work period.

Activity of the biceps averaged 16.1% whereas for the triceps it averaged 38.1%. For pectoralis major, it was 44.2%; rectus abdominus, 10.6%; back extensors, 30.3%; and for the latissimus dorsi, 37.1%. Thus, the muscle was not extensively active during exercise against a 20 pound work load for any of the muscle groups examined. Therefore, it is not surprising that in Figure 13, for the chest press, the average total work was very low. In contrast, as the work load was increased to 40 and 60 pounds (Table 2), muscle use increased. Thus, for the highest work load of 60 pounds, the average work increased to 329.4 work units as shown in the bottom panel above this Figure. The work of the triceps increased to 451.7 and pectoralis major to 441.1 units. Here the greatest muscle activity was only during 25% of a given contraction cycle when concentric work was at its greatest.

During initial flexion, sustained lifting and eccentric contraction, muscle activity was low. Thus by normalizing the work over a 25-second period as was done in Figure 13, the total work over that period of time was substantially lower than that of any of the isometric series of contractions ($P < 0.01$). Therefore total work was about 25% of that of an isometric contraction even against 60 pounds of weight on the chest press exercise machine. For example, for the heaviest work load, the greatest muscle activity was seen for the triceps which was 97% active. However, since it was only active less than 25% of time, total work was low over this period.

Muscle Use During Isometrics- Series 3

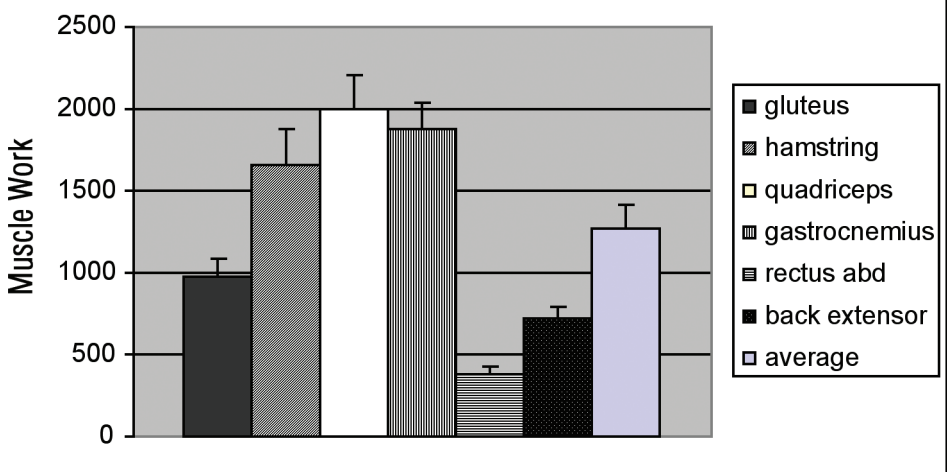
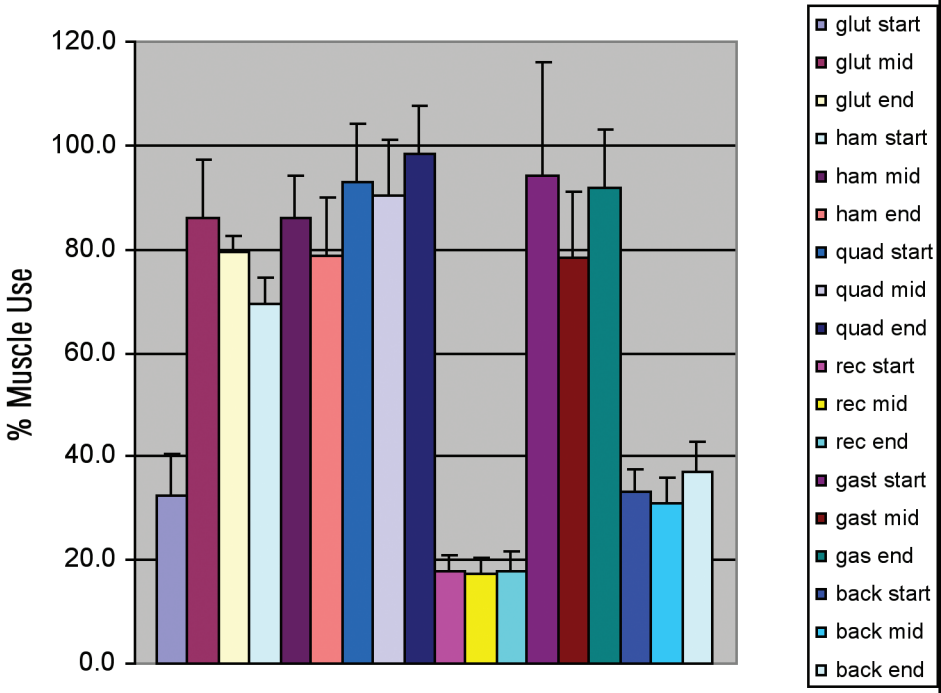


Figure 11. This graph shows, in the upper panel, the percent muscle use for the gluteus maximus, hamstring, quadriceps, rectus abdominus, gastrocnemius, and back extensor muscles at the start, middle, and at the end of the sustained isometric co-contraction of the leg muscles over a 25-second period. While the upper panel shows muscle use, the lower panel displays the total work accomplished by each muscle group during the 25-second period. Each point is shown with the standard deviation.

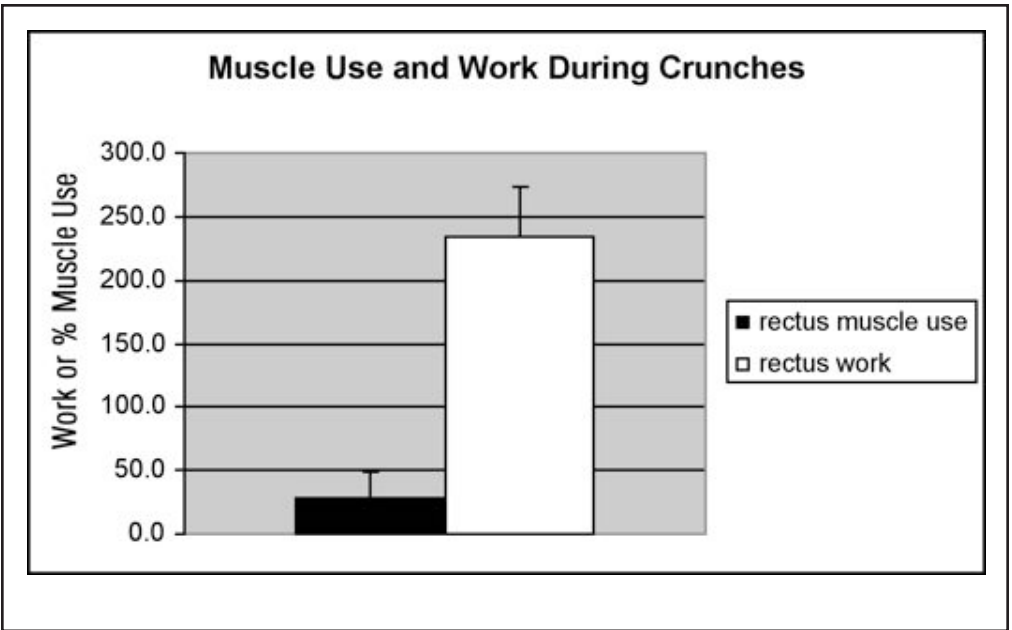


Figure 12. This graph shows the muscle use compared to total work during the crunches over a comfortable 25-second period as that shown in the figures above. Each point is shown with the standard deviation.

The same pattern results were seen for the biceps curl in Figure 14, the triceps curl in Figure 15, and the lat pull down in Figure 16. For the biceps curl, for example, at the heaviest work load, the biceps muscle was 95.3% active. The triceps was 45.4% active whereas the rectus abdominus was 17.9% active. The pectoralis major was 44.6% active and the back extensor muscles were extensively used here and were 71.4% active. This was also true for the lats which were 53.8% active. In spite of this, because of the low duty cycle on work, the total work done for the heaviest work load, only average 280.3 work units whereas at the lowest load the work was 181.7 work units.

For the triceps, as might be expected, the greatest muscle activity was for the triceps exercise (Figure 15) with the heaviest resistance. The pectoralis major showed the greatest work load, averaging 79.8% of muscle activity, whereas back extensors average 51.6% and lats 67.0% of muscle activity. This corre-

sponded to average work for the triceps averaging 294.5 units at the lowest work load and 524.3 units for the heaviest work load. The average of all the muscle group however, even if the heaviest work load was 331.3 work units. The same basic results were seen for the lat pull down. For the lat pull down (Figure 16), even at the heaviest work load, the lats were 96.8% active but there was also activity in the biceps and triceps and back extensor muscles. Back extensors were 63.3% active whereas the triceps were 59.3% active. This translated to a work for the lats of 326.4 units for the lightest work load, 304.4 units for the moderate work load and 335.2 units for the heaviest work load. Oddly enough, the triceps average was 524.3 units for the heaviest work load during the lat pull down exercise. However, the average work over the 25-second period was only 331.3 units even for the heaviest work load.

Similar results were seen for the lower body exercises. These are shown

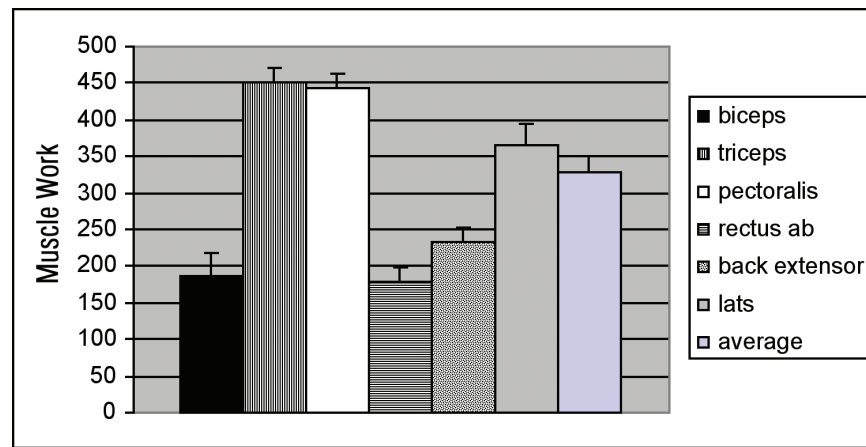
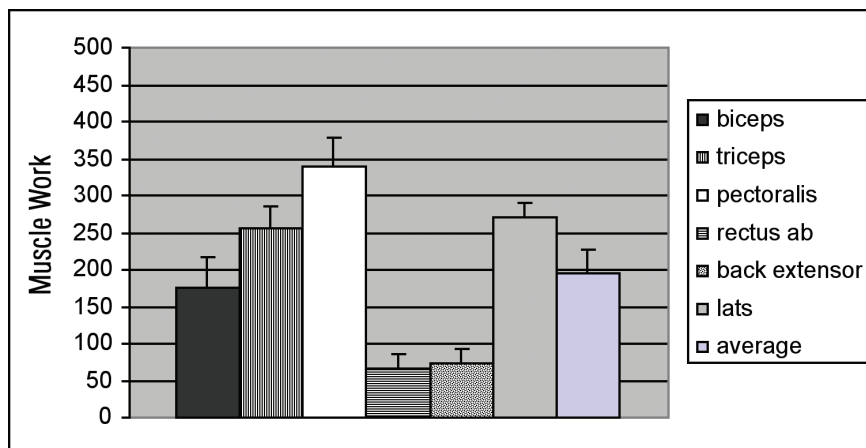
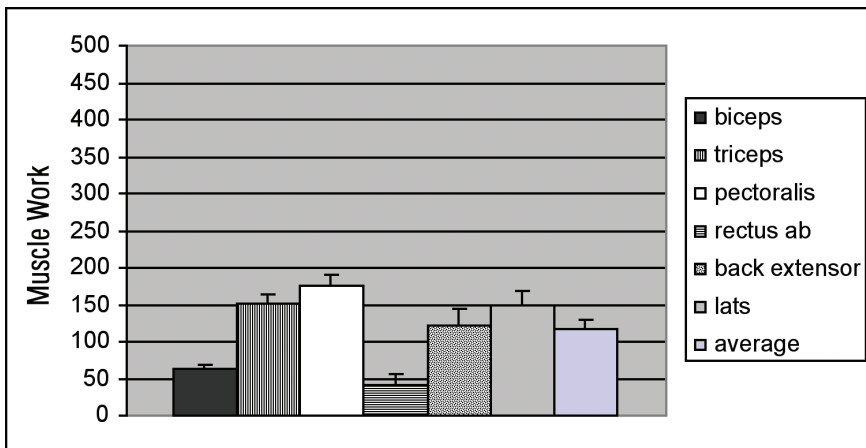


Figure 13. This graph shows the average work for the biceps, triceps, pectoralis major, rectus abdominus, back extensors, latissimus dorsi and the average of all muscle groups during 25 seconds of exercise on the chest press for the low work load (upper panel) moderate work load (middle panel), and heaviest work load (lower panel). Each point is shown with the standard deviation.

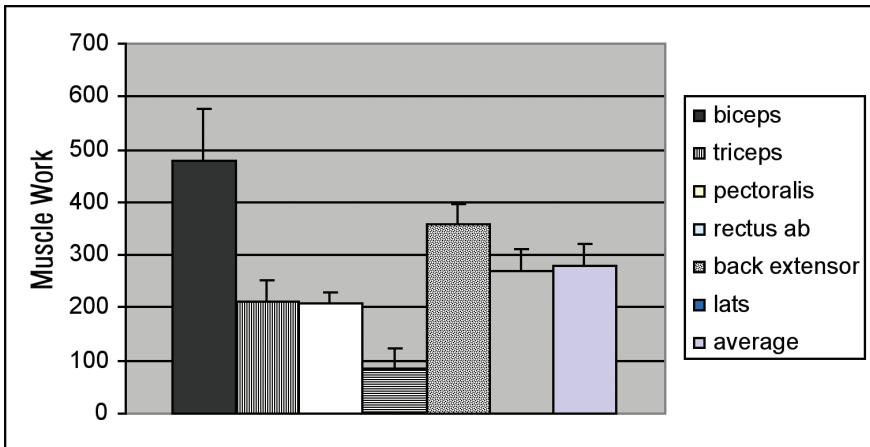
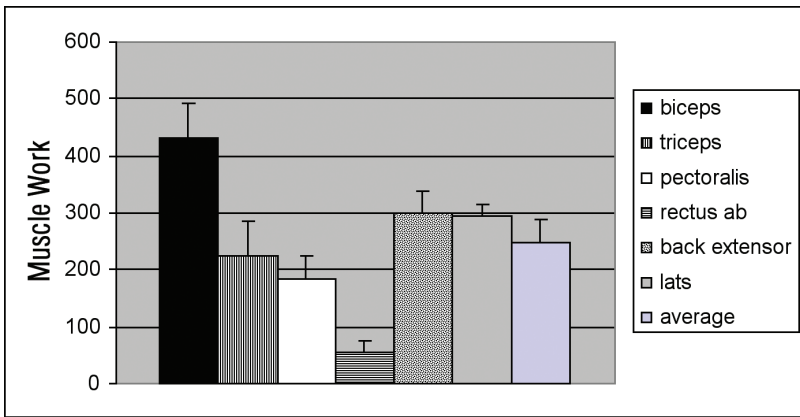
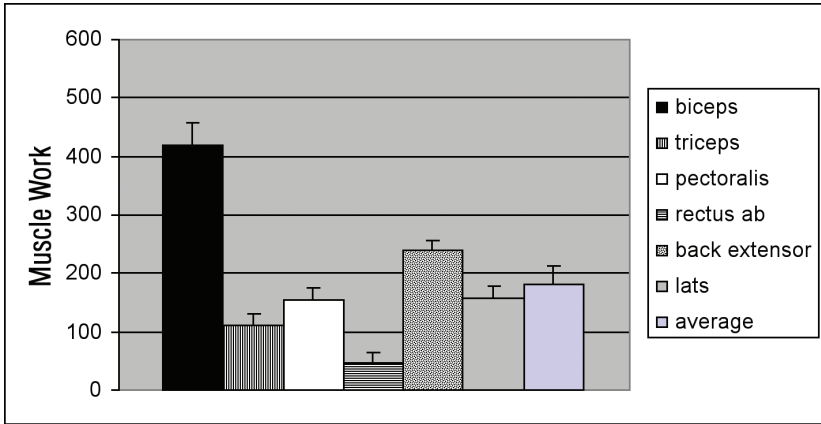


Figure 14. This graph shows the average work for the biceps, triceps, pectoralis major, rectus abdominus, back extensors, latissimus dorsi and the average of all muscle groups during 25 seconds of exercise on the biceps curl for the low work load (upper panel) moderate work load (middle panel), and heaviest work load (lower panel). Each point is shown with the standard deviation.

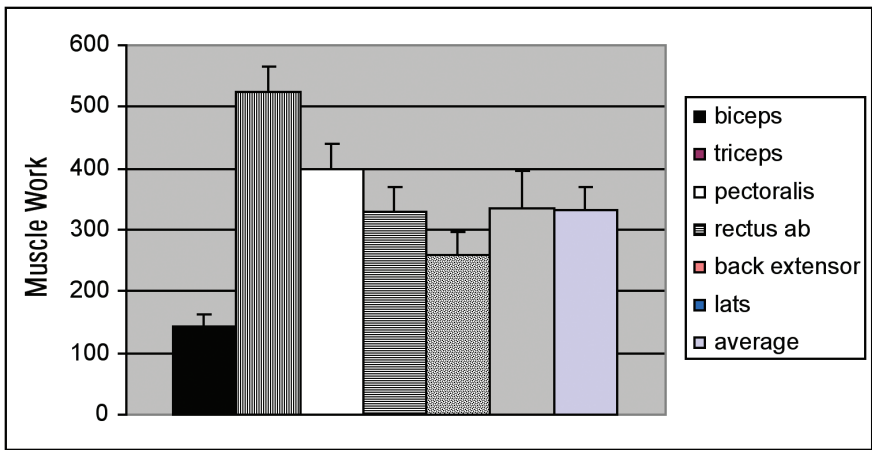
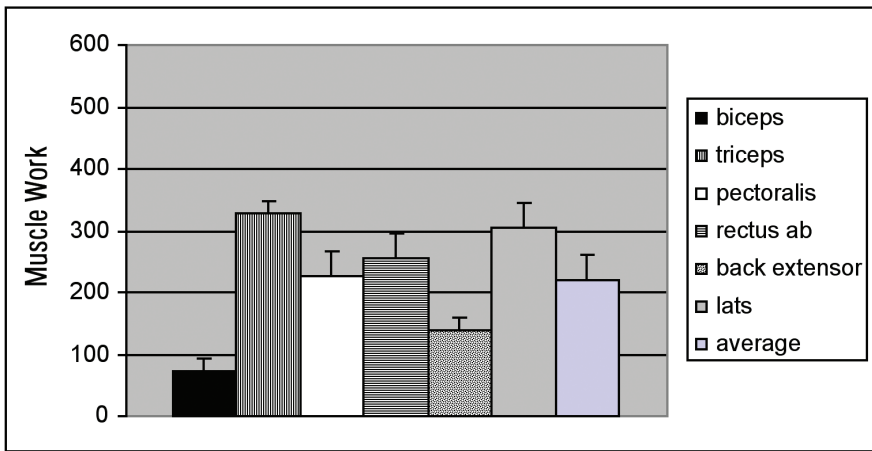
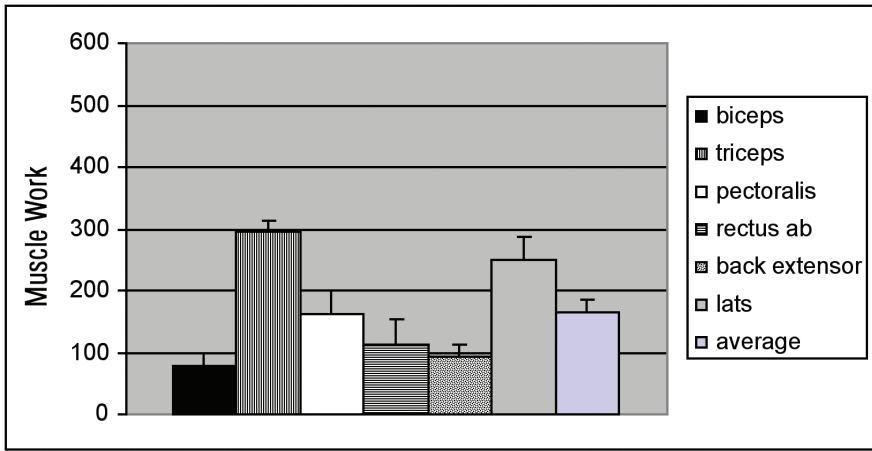


Figure 15. This graph shows the average work for the biceps, triceps, pectoralis major, rectus abdominus, back extensors, latissimus dorsi and the average of all muscle groups during 25 seconds of exercise on the triceps curl for the low work load (upper panel) moderate work load (middle panel), and heaviest work load (lower panel). Each point is shown with the standard deviation.

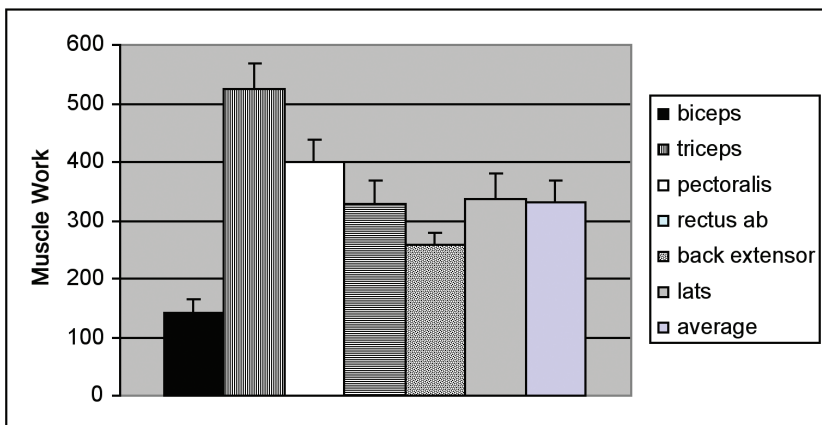
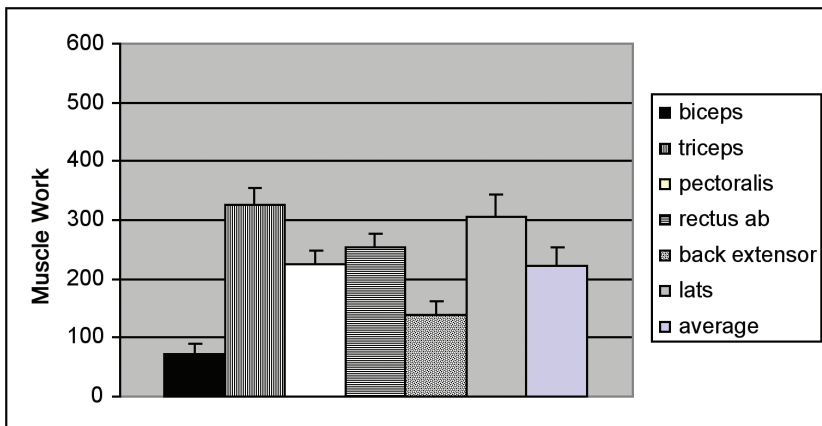
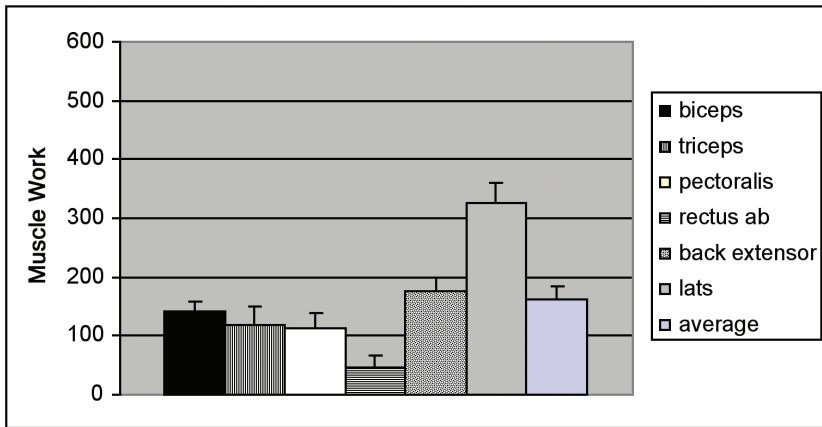


Figure 16. This graph shows the average work for the biceps, triceps, pectoralis major, rectus abdominus, back extensors, latissimus dorsi and the average of all muscle groups during 25 seconds of exercise on the lat pull down for the low work load (upper panel) moderate work load (middle panel), and heaviest work load (lower panel). Each point is shown with the standard deviation.

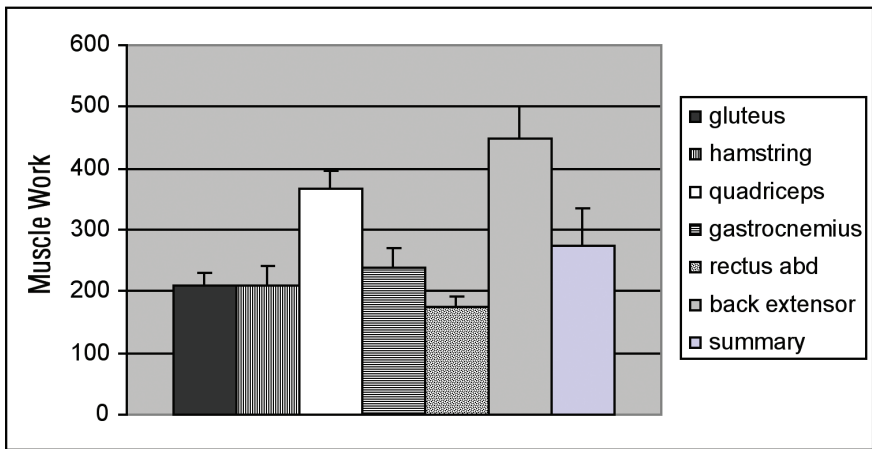
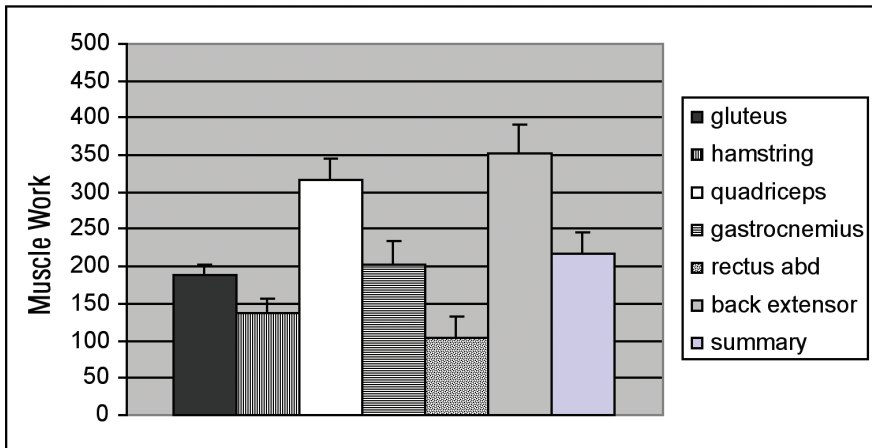
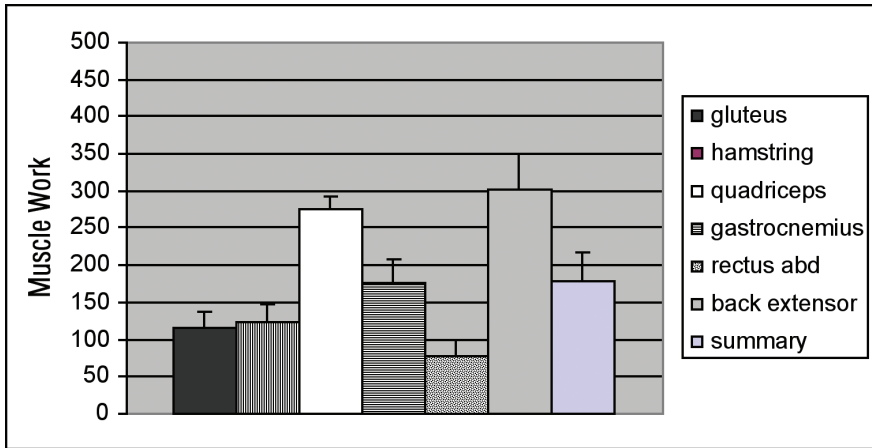


Figure 17. Illustrated here is the muscle work in the gluteus maximus, hamstring, quadriceps, gastrocnemius, rectus abdominus, and back extensor muscles as well as the average for the group (summary) showing muscle activity during a leg press of the low (upper panel) moderate (middle panel) and heaviest (lower panel) workloads. Each point is shown with the standard deviation.

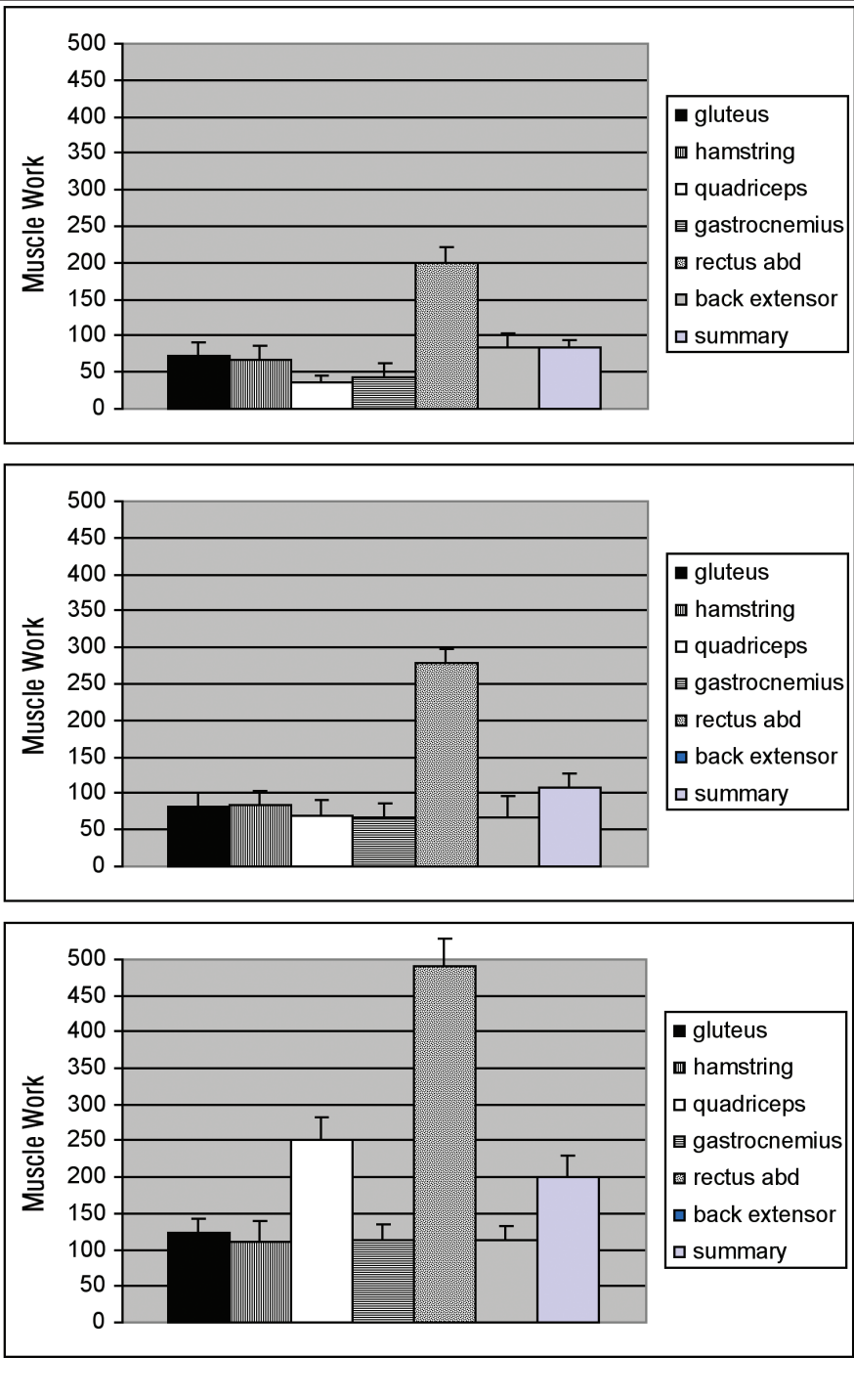


Figure 18. Illustrated here is the muscle work in the gluteus maximus, hamstring, quadriceps, gastrocnemius, rectus abdominus, and back extensor muscles as well as the average for the group (summary) showing muscle activity during abdominal flexion exercises of the low (upper panel), moderate (middle panel), and heaviest (lower panel) workloads. Each point is shown with the standard deviation.

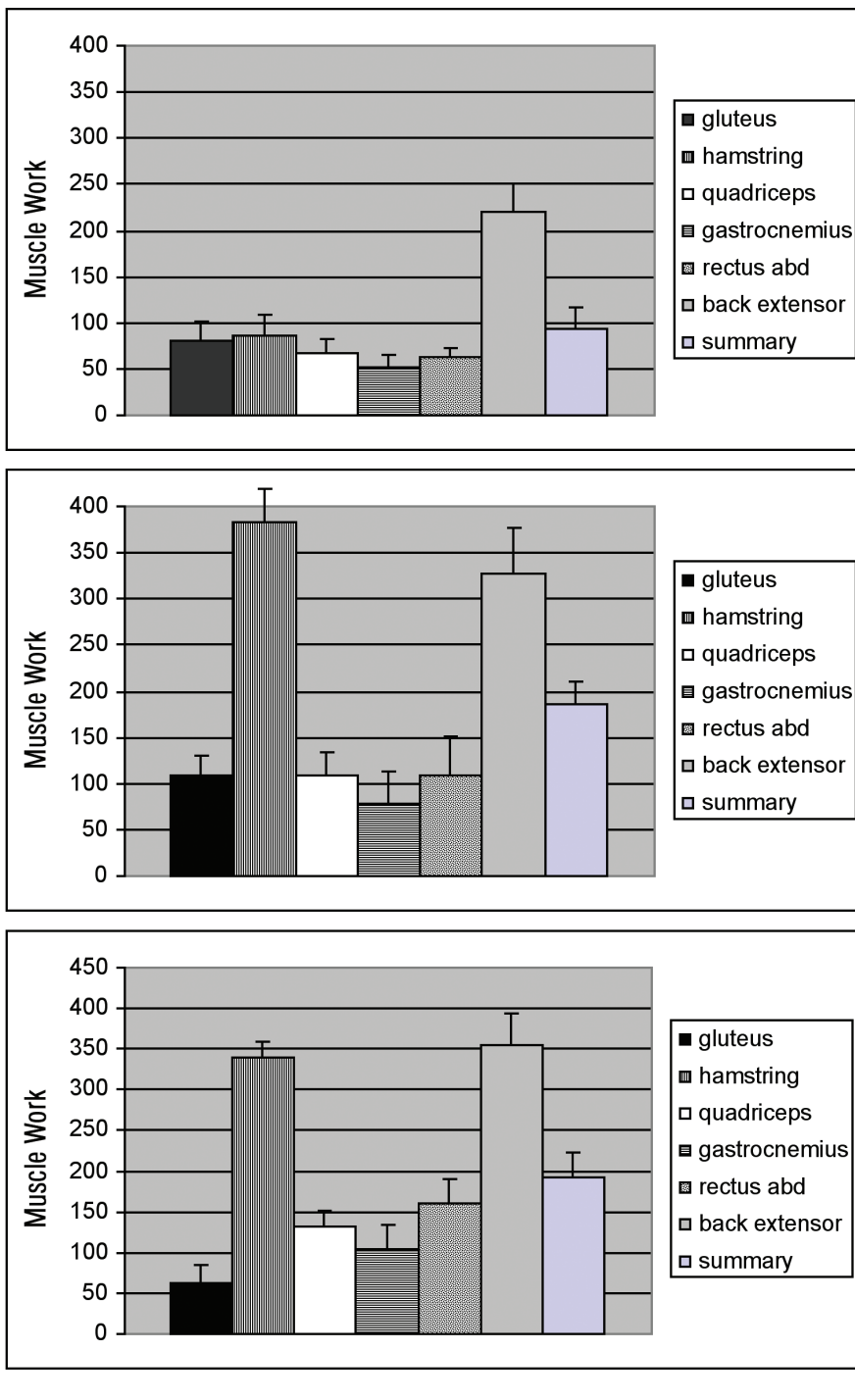


Figure 19. Illustrated here is the muscle work in the gluteus maximus, hamstring, quadriceps, gastrocnemius, rectus abdominus, and back extensor muscles as well as the average for the group (summary) showing muscle activity during back extension exercises of the low (upper panel), moderate (middle panel), and heaviest (lower panel) workloads. Each point is shown with the standard deviation.

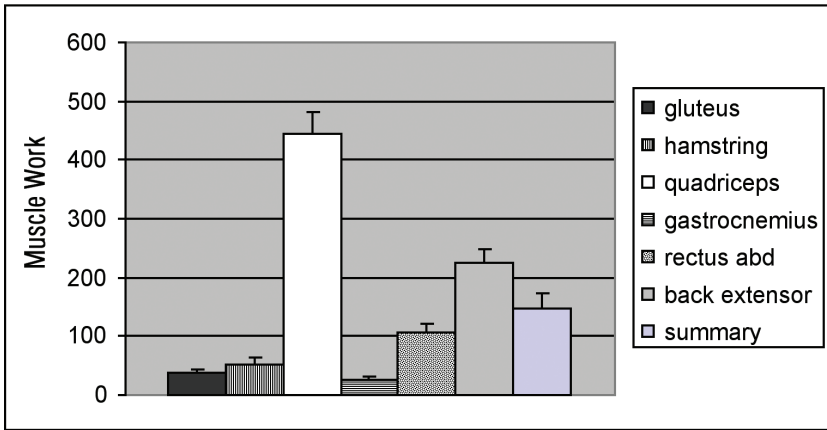
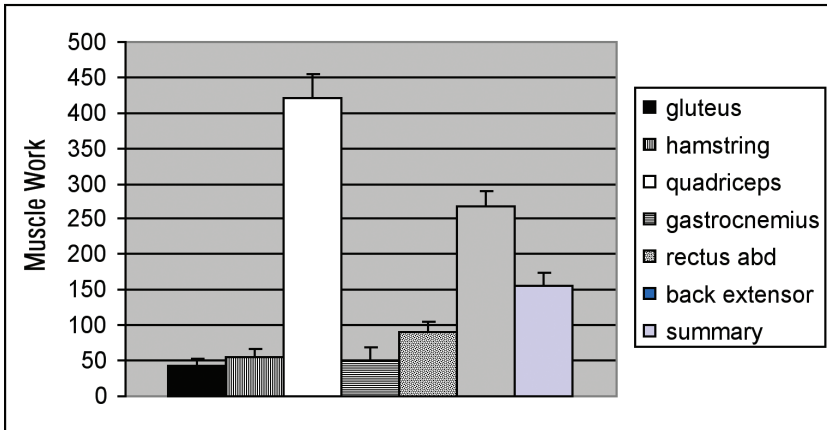
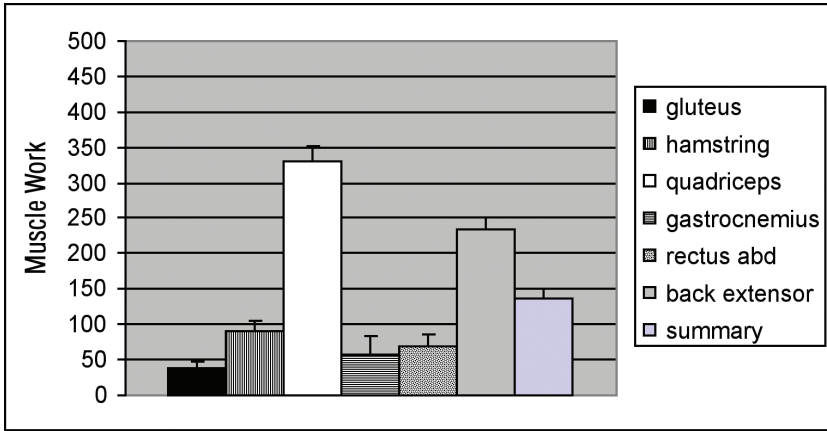


Figure 20. Illustrated here is the muscle work in the gluteus maximus, hamstring, quadriceps, gastrocnemius, rectus abdominus, and back extensor muscles as well as the average for the group (summary) showing muscle activity during knee extension exercises of the low (upper panel), moderate (middle panel), and heaviest (lower panel) workloads. Each point is shown with the standard deviation.

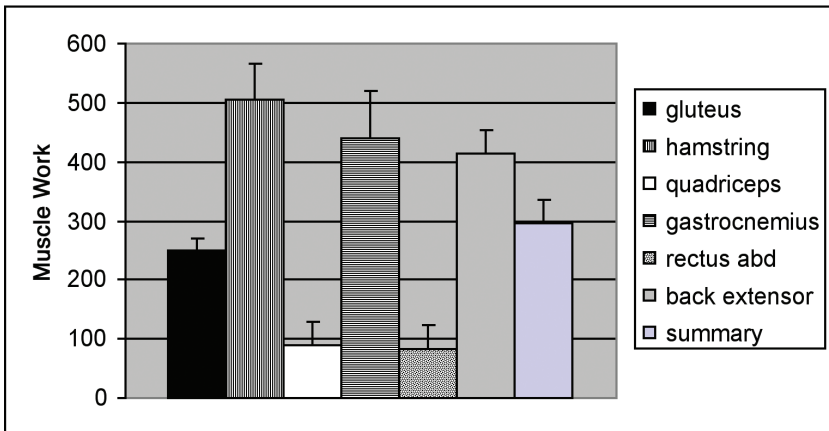
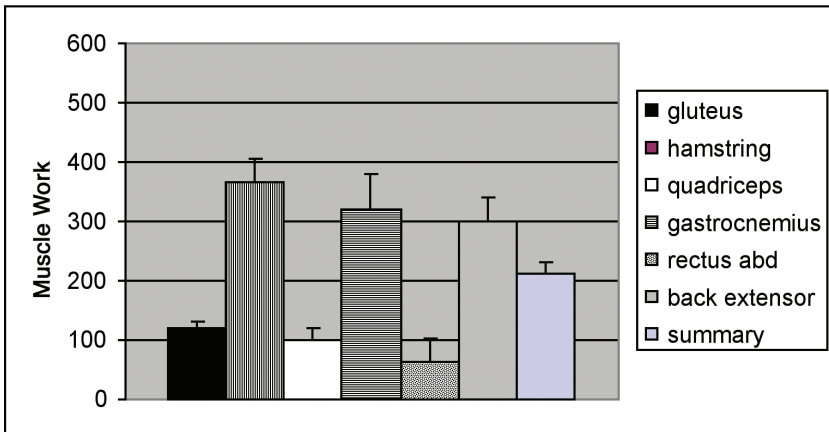
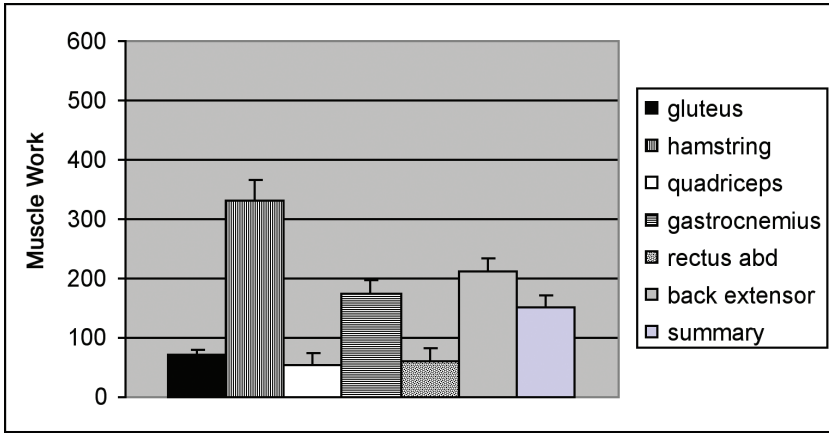


Figure 21. Illustrated here is the muscle work in the gluteus maximus, hamstring, quadriceps, gastrocnemius, rectus abdominus, and back extensor muscles as well as the average for the group (summary) showing muscle activity during hamstring flexion exercises of the low (upper panel), moderate (middle panel), and heaviest (lower panel) workloads. Each point is shown with the standard deviation.

Table 3. Equivalent Crunches to Isometric Exercise

Exercise Set	1a	2	3	Crunch
Work 25 seconds	1375	556	374	233
Work 2 minutes	6600	2592	1795	1118
Equivalent crunch	212	87.8	58	36
6-minute total			444	108

in Figure 17 (leg press), Figure 18 (abdominal flexion), Figure 19 (back extension), Figure 20 (knee extension), and Figure 21 (hamstring flexion exercises). As shown in Figure 17, for the leg press, even at the heaviest work load, the average muscle activity was greatest for the back extensor muscles. This averaged 76.5% muscle activity followed by the quadriceps muscle which averaged 73.3% muscle activity whereas the other muscles (gluteus maximus, hamstring, and rectus abdominus) averaged less than 45% muscle activity even with heaviest work load. The average work for the leg press accomplished over the 25-second period for the lowest work load was 178 units. The work increased to 216.7 units at the moderate work load and to 275.1 units at the heaviest work load. Total work over the 25-second period was significantly less than during any of the isometric exercises ($P < 0.01$).

As shown in Figure 18 for the abdominal flexor exercises, total work increased from 83.6 units to a maximum of 200.6 units for the heaviest work load even though the rectus abdominus muscles average 489.9 work units due to their high activity. Rectus abdominus muscles averaged 95.6% muscle activity at the heaviest work load. However, the rest of the muscles examined in the body worked little during this exercise.

As shown in Figure 19, similar results were seen for the back extensor exercises. The back extensors work start-

ed at 219 units and increased to 354 units of work and were almost fully active during the heaviest work load averaging 70.8% of muscle activity. They and the hamstring muscles contributed most to the total work which averaged 192.5 units during exercise of the heaviest work load.

As shown in Figure 20, for the knee extension exercises, the quadriceps was the most active muscle. The work started at 329.4 work units for the lightest work load and, for the heaviest work load, averaged 443.8 work units. Most other muscles except the back extensors were quiescent. Back extensor activity was approximately half that of the quadriceps muscle increasing the total work to 148.3 units for the 25 seconds of exercise.

As shown in Figure 21, similar results were seen for the hamstring flexion exercises. As would be expected, for the hamstring muscle exercises, the hamstring was most active muscle group starting at 332.5 work units for the lightest work load. However, to support activity of the hamstring muscles, the back extensors were also used with an average of 210.2 work units as was the gastrocnemius muscle an average of 175.1 work units. For the heaviest work load, (see Table 2) hamstring work had increased to 505.9 work units, gastrocnemius work was 439.0 work units, and back extensors was 413.1 work units, yielding an average work over the 25-

Table 4. Equivalent Workloads on Commercial Equipment Compared to Isometric Exercise

	Maximum Work								
	Isometric Series	Work Series	Muscle Group	Low Load	Medium Load	High Load	Low	Medium	High
Chest Press	Series 2	2417	triceps	152	255	451	15.9	9.5	5.4
Biceps Curl	Series 2	2380	biceps	418	431	476	5.7	5.5	5.0
Triceps Curl	Series 2	2417	triceps	294	327	524	8.2	7.4	4.6
Lat Pulldown	Series 2	1357	lats	326	328	335	4.2	4.1	4.1
Leg Press	Series 2a	2040	back extensor	300	352	449	6.8	5.8	4.5
Abdominal Flex	Series 1a	1375	rectus abdominus	200	277	489	6.9	5.0	2.8
Back Extension	Series 1a	1910	back extensor	219	327	354	8.7	5.8	5.4
Quadriceps Flexion	Series 3	1996	quadriceps	418	431	443	4.8	4.6	4.5
Hamstring	Series 3	1662	hamstring	332	365	505	5.0	4.6	3.3
Leg Press	Series 3	1388	gluts	115	188	210	12.1	7.4	6.6

second period of 296.7 work units.

DISCUSSION

By sustaining a contraction continuously (isometric exercise), numerous phenomena occur in muscle. First, blood flow is partly or fully occluded. Unlike dynamic exercise where muscles contract and relax and pump blood actively back to the heart,⁴¹ by sustaining continuous isometric tensions, the intramuscular pressure increases in muscle in proportion to tension.⁴¹ Tension in muscle (intramuscular pressure) as high as 1400 mmHg has been reported in muscle during isometric exercise.^{42,43} This in itself limits blood flow to muscle. When intramuscular pressure exceeds arterial pressure blood cannot perfuse muscle through the arteries. In addition, in some muscles, the mechanical force of the tendons and fascia above the muscle actually nip the arteries causing occlusion of the circulation. For example, in the handgrip muscles, for contractions up to 70% of a muscle's maximum strength, there is still some blood flow during the exercise.⁴⁴ In

contrast, for muscles such as the gastrocnemius, which are in a pennate arrangement, very high forces are developed in the muscles. In these muscles, any contraction above 40% of the muscle's maximum strength results in complete occlusion of the circulation.⁴⁵ Thus, muscles exercising isometrically exercise largely anaerobically and thus the fuel used within the exercising muscle can not be fats or proteins and must be glucose and glycogen during the exercise.^{46,47} Some of the lactate during the exercise requires aerobic metabolism of fats in the liver. After the exercise, the balance of the lactate produced in muscle and the energy depletion from the exercise is replenished by burning fat.⁴⁶⁻⁴⁸

With the mitochondria deprived of oxygen, free oxygen radicals generated by products such as hydrogen peroxide enhance the production of nitric oxide in the mitochondria. Reduced ATP levels cause the production of AMP (adenosine mono phosphate) and activated protein kinase.^{49,50}

Sustained isometric contractions for

as long as 20 to 30 seconds have been associated with increases in the synthesis of actin and myosin in the muscle,^{4,12} probably mediated by these same pathways. This short reduction in cellular ATP concentration seems to be pivotal in strength training. Rhythmic exercise, while increasing metabolism, does little to deplete ATP and increase muscle strength.⁵¹

However, for isometric training to be effective, it must be muscle specific. In other words, a single muscle must become active and sustain a contraction to train.⁴ The normal scheme in the central nervous system is when one muscle fatigues, other muscles are used.^{51,52} By substituting other muscles, fatigue is minimized. This is a contraindication to what would be best for muscle training. For muscle training, we would like to totally fatigue muscles, whereas for normal muscle use, the central nervous system tries to prevent fatigue in muscles. By forcing continuous muscle activity, multiple muscle groups fatigue.

In the present investigation, sustained isometric contractions were accomplished with agonist and antagonist pairs. This offers several advantages. First, weights or heavy exercise equipment is not needed for exercise. For airline travelers or even pilots, light exercise programs have been recommended which can be accomplished while seated.^{53,54} The limbs are simply moved in circles and, with no load on muscle, little training can be accomplished. With isometrics, exercise could be accomplished by using agonist and antagonist pairs. This type of exercise could condition both muscle¹⁴ and the cardiovascular system.⁵⁵ Thus, whether simply using the leg muscles for isometric training for travelers and airline pilots, all the muscles in the body can be exercised. This is also true for space flight. For space flight, exercise has always been an issue since there is

severe atrophy of muscle associated with living in microgravity environments.¹⁶ However, agonist and antagonist pair co-contraction would be quite useful for the space program. Third, sedentary individuals who have limited mobility and difficulty exercising on the floor would find this type of exercise easy to accomplish with good therapeutic benefits.

In the present investigation, for the 3 different agonist and antagonist exercises examined, the muscle use was very broad and continuous compared to commercial weight lifting equipment. For abdominal crunches, as shown in Table 3, the work for the 25-second period for the rectus abdominus muscles during crunches and for the set 1a, 2 and 3 isometric contractions for the same muscle group is shown. For a given 25-second period, the work accomplished by the subjects during abdominal crunches was as much as 5 times less when compared to the work for the 3 isometric regimes. The isometric protocols, while 25 seconds long, were repeated 4 times over a 2-minute period. Extending that work to 2 minutes and then examining the total work over the 6 minute workout with all 3 exercises, the total work was 10,987 units during the 6-minute period with the 3 isometric exercise regimes but only 3,354 work units for the crunches. Over a 6-minute period, if crunches were done continuously at the rate that the subjects exercised here, they would have done 108 crunches. In the same 6-minute period, with the isometric protocol, the equivalent work on the rectus abdominal muscles was equal to 444 sit ups.

A similar situation was seen for the commercial weight lifting equipment. To begin with, isometric exercise utilizes more muscle groups than the limited number of muscles that are exercised either during sit ups or during exercise on the commercial weight lifting equipment. However, looking at a single mus-

cle groups, Table 4 shows only the one muscle group with the greatest activity of all muscles examined and for each exercise. Activity is listed as work done in the 25-second period. Work is shown for the low, medium, and high work loads. The muscle group that exercised the most for a given exercise is also listed. These data are compared to the data from the isometric exercise. The exercise set that exercised the same muscle group the most is listed and the work from that data base is also shown. Finally, the isometric exercise for that group is compared to the commercial weight lifting equipment exercise as a ratio of isometric work to commercial weight lifting work on the same muscle group. As shown in Table 4, the series 1a, 2, 2a, and 3 exercises caused between 4.1 and 15.9 times the exercise for different muscle groups than did commercial weight lifting equipment. While this is interesting in itself, when added to the fact that more muscle groups exercise with isometric than the commercial equipment, the isometric protocol is a much better form of exercise. In fact, using isometric exercise for 6 minutes would be the equivalent muscle work of 30 to 35 minutes of gym work on commercial weight lifting equipment.

Thus, the isometric co-contraction of muscle used in these experiments was an excellent method of exercising muscle. It offers the advantage of not relying on commercial exercise equipment. Further, for sedentary people who would have a difficult time lying on the floor, the exercise can be done standing. This type of exercise can be done by someone traveling or almost anywhere. It is short in duration so that it does not take much time to accomplish.

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