To the Graduate Council:

I am submitting herewith a thesis written by R. Christopher Spruiell entitled "Increases in the Exercise Capacity of the Arms Following an Endurance Training Program With the Legs." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Physical Education.

Edward T. Howley

Edward T. Howley, Major Professor

We have read this thesis and recommend its acceptance:

Ronald H. Cox

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Accepted for the Council:

Vice Provost
and Dean of The Graduate School

INCREASES IN THE EXERCISE CAPACITY OF THE ARMS FOLLOWING AN ENDURANCE TRAINING PROGRAM WITH THE LEGS

A Thesis

Presented for the

Master of Science

Degree

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R. Christopher Spruiell

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DEDICATION

To my parents, Ralph and Peggy Spruiell, who loved me, supported me, and believed in me, throughout the many phases of my life.

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ABSTRACT

Many studies have shown increases in the physical work capacity ($\dot{V}O_2max$) and reductions in the heart rate (HR) response to submaximal exercise after endurance training with the legs. However, a controversy remains as to whether these adaptations can be seen in the arms following leg training. The purpose of this study was to determine if "transfer effects" occur in the arms when only the legs are used during endurance training. A control (no exercise) group was used as a reference group for two (exercise) groups. One treatment group exercised while holding on to the handle bars while the other held their hands at their sides. Eighteen volunteers were used as subjects in the study. The subjects exercised at an intensity equal to 85-90% of their maximal heart rates for 30-minutes per session, 4 days per week for 4 weeks. Arm and leg cycle ergometer tests were used to measure maximal aerobic power ($\dot{V}O_{2max}$) with the arms and the legs, respectively. Maximal testing was conducted prior to and following the 4 week training period.

An analysis of variance (ANOVA) was computed for group comparisons to determine differences between the pre- and postmeasures for respiratory exchange ratio values, maximal $\dot{V}O_2$, maximal heart rate, and maximal workloads. The analysis indicated that no "transfer" to the arms occurred for either of the experimental groups ($p > 0.05$). A significant difference did exist among the leg $\dot{V}O_{2max}$ values for the trained groups when compared to the control group ($p < 0.05$). Increases in leg

and arm $\dot{V}O_{2max}$ values for group 2, were 10.3% and 6.6%, respectively, and for group 3, 11.0% and -1.0%, respectively. No significant differences were found when comparing groups 2 and 3.

It was concluded that further work is needed in the area of cross transfer. The recommendation calls for an experimental design that is conducted at the proper intensity (85-90% of maximal heart rate), frequency (4-5 days per week), and duration (10-11 weeks), while attempting to carefully isolate the arms from involvement during leg training.

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CHAPTER 1

INTRODUCTION

Many studies have shown increases in the physical work capacity ($\dot{V}O_{2max}$) and reductions in the heart rate (HR) response to submaximal exercise after endurance training on cycle ergometers. Investigators have consistently found that these adaptations occur in response to exercise in the legs. However a controversy remains as to whether these adaptations can be seen in the arms following leg training. Many investigators believe that these "limb specific" training effects result from peripheral adaptations, such as the enhanced activity of oxidative enzymes in the trained muscles. Other investigators argue that endurance training causes changes in the heart itself, the central circulatory system, or the central nervous system. Those who support the theory of central training effects would say that one or more of these central cardiovascular (CV) adaptations cause the increase in $\dot{V}O_{2max}$ or the reduction in HR during submaximal exercise. The researchers who take this position have reported "transfer effects" following endurance training, i.e., increases in $\dot{V}O_{2max}$ and/or a reduced submaximal exercise HR response in the arms following leg training. Such improvements in the exercise capacity of untrained limbs have been used as evidence for central circulatory adaptations to endurance training (Lewis, Thompson, Areskog, Vodak, Marconyak, DeBusk, Mellen, & Haskell, 1980).

Many controversies remain in the literature about whether or not the increases in $\dot{V}O_{2max}$ and/or reductions in submaximal exercise HR are caused by peripheral or central adaptations. Therefore, further research that is designed to address this issue is needed. A critical analysis of studies that have shown "transfer effects" to the untrained limbs following endurance training, has indicated that problems may exist in the experimental designs. These studies have shown improvments in the arms following leg training possibly because the arms were not isolated during leg training. The subjects were allowed to hold on to the handle bars while training on cycle ergometers (Rosler, Conley, Claassen, & Howald, 1985; Lewis et al. 1980). Research has shown that during ordinary cycling, when subjects hold on to the handle bars, up to 10-20% of the total power output is supplied by the arms (Nagle, Richie, & Giese 1984). Therefore, the arms are clearly being used during the "leg training" sessions which may account for the "transfer effects".

The purpose of this study was to determine if "cross transfer" does occur to the arms when only the legs are involved in endurance training.

CHAPTER 2

REVIEW OF LITERATURE

Many of the training studies designed to test for "transfer effects" have been done with one- and two-leg training. Saltin, Nazar, Costill, Stein, Jansson, Essen, and Gollnick (1976) attempted to look at the training effects of one-legged cycling. They worked with untrained students averaging 22 years of age. Group A trained both legs separately. One leg was trained for endurance (E) by continuous cycling for 30-50 minutes per session and the other leg trained with sprint (S) training by repeated all-out efforts for 30-40 seconds with 60 to 90 seconds of rest between exercise bouts. Group B trained one leg with the (S) training, while the other leg remained untrained and group C trained one leg with the (E) training, while the other leg remained untrained. Cycle ergometers were used both for testing and for training. The only special arrangement for one-legged exercise was made in securing the foot to the pedal with a toe clip with an elastic band around the heel. The training period lasted for 4 weeks with an average of 5 workouts per leg each week. The workloads were chosen to represent approximately 75% (E) and 150% (S) of the one-legged $\dot{V}O_{2max}$. The workloads and duration for endurance and sprint training were chosen so that the total amount of work done with each leg was similar. In group A, where the endurance training of one leg was followed by sprint training of the other leg, a 5-10% shorter training period was used for each leg as compared to groups B and C. The work performed amounted to approximately 700 Kcals each week per trained leg. However, group A performed about 90-95% more work than group B because both legs were trained. It took up to 90 minutes per day to complete the S training due to the 60-90 seconds of rest allowed between each sprint.

In group A, the $\dot{V}O_{2max}$ increased by 11% and 20% in the S and E trained legs, respectively. In group B, the S training resulted in a 15% increase whereas the inactive leg only changed by 3%. In group C, the E training produced a 24% increase of $\dot{V}O_{2max}$ in the trained leg and a 6% increase in the nontrained leg.

Along with these $\dot{V}O_{2max}$ changes, Saltin et al. (1980) found that the exercise caused increases in the oxidative potential of the muscle fiber through changes in the oxidative enzyme activities of the muscles. Furthermore, Saltin et al. (1980) found that a lowering of the HR at submaximal exercise occurred with the trained leg but not with the untrained leg. These findings led Saltin to conclude that the lowering of the HR at submaximal exercise was related to perpherial adaptations.

The idea that perpherial changes are responsible for causing the drop in HR during submaximal exercise in the trained leg and not the untrained leg has been adopted by many researchers over the past several years, e.g., during one-legged experiments. However, such a conclusion may be challenged. One proposed explanation for this specific training effect could be that training with one leg does not represent a sufficient stimulation of the cardiovascular (CV) system to produce central circulatory changes (Clausen, 1977).

Davies et al. (1975) supported Clausen (1977) in a study where a group of subjects were trained for 60 minutes/day (30 minutes with each leg), 3 times per week over a 5 week period. The subjects worked at an intensity of 80% of their (one-leg) $\dot{V}O_{2max}$. The subjects were habituated to exercise by performing submaximal exercise during the first four sessions with one leg (left or right), the second four sessions with the other leg, and finally the last three sessions with both legs. Following the period of habituation, definitive submaximal and maximal one- and two-leg exercise measurements were taken. The submaximal and maximal tests were conducted immediately prior to, and following the 5 week training period.

Davies et al. (1975) found that there was a 14% increase in the one-legged $\dot{V}O_{2max}$, while the two-legged $\dot{V}O_{2max}$ had increased by only 4.7%. The stress imposed on each leg during the one-legged exercise was the same or greater than that imposed by the ordinary two-legged cycling. Therefore, the perpherial training effect on the leg muscles can be assumed to be identical in the two situations or possibly greater after training of only one leg. The reason the training effect during the exercise performed with both legs was lower than that when performed with one leg is that training with one leg, even when performed at near maximal levels, did not challenge the CV system sufficiently to induce appreciable central circulatory changes.

Another explanation for the smaller $\dot{V}O_{2max}$ changes for two-legged work when compared to one-legged work is related to the mean blood pressure (MBP) which must remain as high during two-legged exercise as during one-legged exercise. Consequently, during maximal work increases in leg blood flow (LBF) during two-legged exercies are hindered by local vasoconstrictions. Clausen (1977) cited six studies in support of this idea. The studies were focused on pre- and posttraining values for maximal O_2 uptake, maximal cardiac output (CO), and MBP during maximal exercise. Compared with the pre training values, CO and $\dot{V}O_{2max}$ were 12% and 13% higher after training, whereas no significant change occurred in the MBP. On the basis of these findings it seemed justified to conclude that the increase in maximal CO with training was matched with a reduction of the total perpheral resistance (TPR) during maximal exercise, to keep the MBP the same (MBP = TPR x CO).

When endurance training reduces the TPR during maximal work, the CO is increased so that the MBP can remain constant. Such increases in muscle blood flow cause increases in $\dot{V}O_{2max}$ [CO x $(a - v)O_2$ difference = VO_2]. The CO only increases to a point that coincides to the decrease in the TPR because of the maintenance of the MBP. Therefore, the reasons for the increased $\dot{V}O_{2max}$ values for one-legged training over those of two-legged training were because of the ability to vasodilate a large fraction of the muscle mass involved in one-legged exercise. When both legs were used, a greater muscle mass was involved. This demanded a greater proportional vasoconstriction to maintain MBP (Clausen, 1977).

The position taken by Clausen (1977) is supported by studies that have shown reductions in blood flow and O_2 uptake in the legs when severe arm exercise is added to ongoing heavy leg exercise (Secher, Clausen, Klausen, Noer, & Trap-Jensen, 1977; Secher, Ruberg-Larsen, Binkhorst, & Bonde-Petersen, 1974). Secher et al. (1977) reported that the $\dot{V}O_{2max}$ during leg exercise was only slightly increased by the addition of arm exercise. Secher et al. included subjects who performed leg training on a leg ergometer positioned vertically under the saddle, with an arm ergometer positioned in front of them. This enabled the arm cranking to be performed in a horizontal position. The subjects represented an above average state of physical conditioning and they were familiar with strenuous dynamic exercise. Each subject performed two 20-minute exercise periods per training session. During the first 10 minutes of the first period the subjects exercised with the legs alone or with the arms alone. Thereafter, arm exercise or leg exercise, respectively, was superimposed onto the ongoing exercise. The combined bouts of exercise were continued for the remaining 10 minutes of the first session. For each subject the workloads were chosen so that complete exhaustion occurred by the end of each 20-minute exercise period.

The second 20-minute exercise period was performed after 60 minutes of supine rest. The protocol and the workloads were the same as in the first period, except that the subjects who had started with leg exercise in the first period started with arm exercise in the second and vice versa. On the average, 36% of the total work output during combined exercise was performed with the arms. Expressed as a percentage of $\dot{V}O_{2max}$ for the respective types of exercise, the relative $\dot{V}O_{2max}$ during arm exercise was 44%, the relative $\dot{V}O_{2max}$ during leg exercise was 67%, and the relative $\dot{V}O_{2max}$ during combined exercise was 77%.

The main finding in Secher et al. (1977) study was that superimposing a sufficiently strenuous arm exercise onto ongoing heavy leg exercise caused a reduction in blood flow as well as a reduction in O_2 uptake in the exercising legs. Likewise, the changes in $(a-v)O_2$ difference in the arms during the transition from arm exercise to combined exercise caused a reduction in the blood flow in the exercising arms. The reduction in leg blood flow (LBF) when arm exercise was added occurred with no change in the MBP. The decrease in flow with an unchanged MBP implied an increase in the vascular resistance in the exercising legs. Part of this may have been caused by reinforced sympathetic vasoconstriction in the nonexercising tissues, but the decrease in O_2 uptake in the legs indicated that the active muscles were also affected.

Secher et al. (1977) found that superimposing exercise with extra muscle groups may counteract the metabolic vasodilation and mediate vasoconstriction even in the muscles performing the exercise. Beyond a certain work intensity and/or muscle mass involvement, several muscle groups exercising at the same time will limit the O_2 supply to each group, i.e., each muscle group will have a lower blood perfusion than if it performed its share of the total workload alone. The vasoconstriction in the central circulatory system is thought to be controlled by the baroreceptors serving to maintain the MBP. Another possibility is that the vasoconstriction in the exercising muscles is mediated by the same mechanisms as the vasoconstriction in abdominal viscera which probably are elicited by receptors in the exercising muscles.

The reductions in driving pressure to the arms and the increased resistance to flow in the exercising legs during combined exercise, provides two possible explanations for the fact that $\dot{V}O_{2max}$ during combined exercise is not the algebraic sum of the $\dot{V}O_{2max}$ during arm and leg exercise performed separately, and may explain why relatively small increases in $\dot{V}O_{2max}$ are obtained by adding arm work to ongoing leg exercise. While the one-legged training does not utilize a sufficient amount of muscle mass to induce a substantial central circulatory adaptation that will carry over to the untrained leg, there reaches a point where further additions of muscle mass actually inhibit the increases in CV adaptations due to the changes that occur in the periphery (Secher et al., 1977).

These findings confirmed earlier work by Secher et al. (1974) who reported that uphill running on a treadmill elicits a $\dot{V}O_{2max}$ superior to that when arm and leg exercise is done seperately. However, the $\dot{V}O_{2max}$ during uphill running was not significantly different from that obtained during arm and leg exercise combined. These results suggest that a similar muscle mass is involved in uphill running and arm plus leg work.

Nagle et al. (1984) supported the findings of Secher et al. (1974) and Secher et al. (1977) through a study where the subjects did varying degrees of arm work in conjunction with leg work on a cycle ergometer. One group of subjects was instructed to let their arms hang at their sides as they cycled. Another group of subjects was instructed to maintain a 10, 20, and 30% arm contribution to total power in three separate tests of $\dot{V}O_{2max}$ by using progressive exercise to exhaustion on an arm ergometer. A third group was set up to ascertain the $\dot{V}O_{2max}$ values for conditions approximating conventional cycling, i.e., leg cycling without the involvement of the arms. The subjects performed progressive exercise bouts on the cycle ergometer with 100% arms, 100% legs, and combinations of 10% arms/90% legs, 20% arms/80% legs, and 30% arms/70% legs.

Nagle et al. (1984) found that when arm cranking was added to leg cycling, the additional active muscle mass significantly increased the $\dot{V}O_{2max}$ above that measured in leg cycling alone. However, this was true only when the arms contributed 10 to 20% of the total power. When the arms contributed 30% of the total power, the $\dot{V}O_{2max}$ was reduced to a level below the mean attained in exercise with the legs alone. They also found that when the subjects held on to the handle bars (such as during ordinary cycling) the arms contributed up to 10-20% of the total power output and therefore was a factor in influencing $\dot{V}O_{2max}$.

Rosler et al. (1985) reported that not only is it important to have a sufficient amount of muscle mass involvement to produce increases in $\dot{V}O_{2max}$ and reductions in submaximal exerising HR, but the muscle mass involvement also plays a critical role in causing cross transfer to untrained limbs. Rosler et al. (1985) conducted a study on 10 healthy male subjects. None of them had been involved in a regular training program during the preceeding 2 years although some were recreational cyclists or joggers. The exercise training was conducted on mechanically braked FLEISCH cycle ergometers. The training program lasted for an 8-week period and consisted of 5 training sessions per week of 30 minutes each. The workloads were set to allow each subject to exercise at the maximal power output maintainable for the 30 minute period. The workloads were increased periodically to keep the intensity at the same relative level throughout the training sessions. The intensity was judged by the HR achieved at the end of each session, which typically reached 90-95% of the subject's maximal HR.

Rosler et al. (1985) found that a significant "transfer effect" in the arms did occur as a result of endurance training of the legs. The $\dot{V}O_{2max}$ values increased significantly both for leg pedaling (13%) and arm cranking (9%) after the leg endurance training. However, no particular care was taken to prevent the subjects from using their arms during the leg training. The maximal power output also increased significantly after the training for both arm and leg exercise (Rosler et al., 1985).

Lewis et al. (1980) also found increases in the endurance capacity of the arms ("transfer effects") following a training study that involved two-legged cycle training. Lewis et al. (1980) used 10 healthy male college students as subjects. None of the subjects had performed any regualar strenuous physical activity with the arms or legs for at least 6 months prior to the study. Five of the subjects were assigned to perform arm training and 5 were assigned to perform leg training. The leg training consisted of pedaling a cycle ergometer and the arm training consisted of cranking an arm ergometer. For the arm training the cycle pedals were modified to permit comfortable gripping and the ergometers were clamped onto heavy tables. The arm trainers sat in chairs with their feet flat on the floor. No restrictions were placed upon the use of the handle bars during leg training.

The arm training and the leg training groups trained 30 minutes per day, 4 days a week for 11 weeks. The training intensity was set at 75-80% of $\dot{V}O_{2max}$ with the respective exercise modes. The training intensity was monitored by frequently checking the subject's pulse rates and by recording the workload settings on the ergometers.

Lewis et al. (1980) found increases in $\dot{V}O_{2max}$ and reductions in submaximal exercise HR with the untrained as well as with the trained limbs following the 11-week exercise period. After arm training, the HR was reduced from 137 to 111 during exercise with trained arms and from 154 to 137 during exercise with the untrained legs. After leg training, the HR dropped from 140 to 118 during exercise with the trained legs and from 125 to 108 when exercising the untrained arms. The leg cycling and arm cranking $\dot{V}O_{2max}$ values increased 15% and 9% after the leg training and 12% and 35% after the arm training. The degree of transfer was not as great from the trained arms to the untrained legs when comparing the degree of transfer of the trained legs to the untrained arms. These findings again supported the notion that with the increasing usage of muscle mass (up to a certain point) the "transfer effect" will be greater.

Based on the current literature, it is believed that if increases in $\dot{V}O_{2max}$ and reductions in submaximal exercising HR are to be accompanied by "transfer effects", the endurance training program must utilize a sufficient amount of muscle mass to induce central cardiorespiratory adaptations. Thus, many of the one-legged studies show smaller adaptations as compared to the two-legged studies. However, there reaches a point of diminishing returns, at which time the addition of greater amounts of muscle mass actually triggers the vasoconstriction mechanisms in the periphery. This causes an increase in the TPR. The TPR limits the degree to which the CO and therefore the $\dot{V}O_{2max}$ may increase because the MBP must be maintained at a constant level.

Many questions arise about the experimental design of the studies that have shown "transfer effects" to the untrained limbs following endurance training. These studies did not isolate arm involvement during leg training. The subjects were allowed to hold on to the handle bars while training on a cycle ergometer (Lewis et al., 1980; Rosler et al., 1985). Nagle et al. (1984) has shown that when subjects hold on to the handle bars, up to 10-20% of the total power output is supplied by the arms. Perhaps the arms have been used during the "leg training" sessions, which may account for the "transfer effects". The present study was designed to determine if "transfer effects" do occur when the arms are isolated from involvement during leg training.

CHAPTER 3

METHODOLOGY

Description of Subjects

Eighteen college-aged (18-22 years) volunteers with no known health problems were used in the study. Each subject underwent a thorough screening process for possible contraindications for testing and exercise participation. Following the screening process (see Appendix B) a complete explanation of the testing procedures, and study methodology was covered, including a description of the possible discomforts of taking a maximal exercise test. The subjects were instructed to refrain from eating and smoking and from drinking caffeinated beverages 3-4 hours prior to reporting to the laboratory.

All subjects completed arm and leg cycle ergometry tests to determine their $\dot{V}O_{2max}$ prior to and following a 4 week training period. Group 1 consisted of 7 subjects who performed no exercise during the 4 week period. Group 2 consisted of 6 subjects who performed leg exercise on a cycle ergometer while holding their arms at their sides. Group 3 consisted of 5 subjects who performed leg training on a cycle ergometer while holding on to the handle bars.

Pre- and Postexercise Tests

Maximal Oxygen Uptake Tests

Arm and leg cycle ergometer tests were used to measure maximal aerobic power ($\dot{V}O_{2max}$) with the arms and legs, respectively. Maximal testing was conducted prior to and following the 4 week training period. Arm and leg exercise testing were performed on cycle ergometers (Monarch model 662). Both the arm test protocol and the modifications of the cycle ergometer to accomodate arm cranking were taken from Sawka, Foley, Pimental, Toner, and Pandolf (1983). During the maximal arm tests the initial workload on the arm ergometer was set at 0.25 kp and was increased by 0.25 kp every 2 minutes throughout the test. The pedal rate was held at a constant speed of 70 rpm throughout the duration of the test. During the arm tests the subjects sat erect against the chair back with their feet flat on the floor. The chair was positioned so that nearly full arm extension would be achieved when the cranks were horizontal.

The initial workload for maximal leg testing was set at 2.0 kp and the load was increased by 0.5 kp until the test was terminated. The pedal rate during the maximal leg tests was held at 60 rpm. The tests for both the arms and the legs were continued under the guidelines of the above protocol until the subjects had reached a level of voluntary exhaustion.

Maximal Oxygen Uptake Determination

The subjects breathed through a low resistance Daniels type valve. The inspired air volume (V_I L/min) was measured for 1-minute periods with a desk model physiograph (Model DMP-4A, Narco Co./E & M Instrument Co., Inc., Houston, Texas). Fractions of O_2 and CO_2 in expired air were determined with an O_2 analyzer (Model S-3A, Applied Electro-chemistry

Inc., Sunnyvale, California) and a CO_2 analyzer (Model CD-3A, Applied Electro-chemistry Inc., Sunnyvale California). These analyzers were calibrated with known O_2 and CO_2 mixtures validated by Scholander gas analysis. The heart rate was monitored throughout the tests and was determined from a single-lead ECG tracing with the desk model physiograph. During maximal testing expired air was collected in Douglas bags during the last minute of every 2 minute stage and contuniously during the last 3-4 minutes of the tests. $\dot{V}O_{2max}$ (L/min STPD) was calculated from the percentage of O_2 and CO_2 in expired air according to standard formulas. Respiratory exchange ratio, maximal heart rate, and physical appearance were used as guidelines for insuring that true maximal efforts were exerted. The data of any subject who clearly had not reached a maximal level during all leg and arm tests were excluded from the study.

Cycle Training Program

The subjects underwent 4 weeks of endurance training on cycle ergometers while either holding their arms at their sides or on the handle bars. Each week the paticipants were involved in 4 training sessions lasting 30 minutes each. The training intensity was held constant at 85-90% of their maximum heart rate. Adjustments were made in the workloads throughout the training session to ensure that the proper intensity was maintained. Pulse counts were recorded and workloads adjusted at 5-minute intervals throughout the 30 minute training session.

Statistical Analysis

Analysis of variance (ANOVA) procedures and Bonferroni (Dunn) T tests were computed for group comparisons of the differences between the pre- and postmeasures for RER values, maximal VO_2, maximal heart rate, and maximal workloads. (Refer to Appendix A for further information about the statistical results).

CHAPTER 4

RESULTS

Oxygen Uptake

Maximal Oxygen Uptake

Data on maximal oxygen uptake are listed in Table 1. There were no significant differences among the post $\dot{V}O_{2max}$ values for the arms when comparing groups 1, 2 and 3. However, a significance difference did exist between the leg $\dot{V}O_{2max}$ values for the trained groups when compared to the control group ($p < 0.05$). No significant differences were found when comparing group 2 and group 3 (See Appendix A).

Workloads

Maximal Workloads

Data on maximal workloads are listed in Table 2. There were no significant differences between posttest maximal workloads for the arms when comparing groups 1, 2 and 3. However, a significant difference did exist between the maximal workloads for the legs when comparing groups 2 and 3 to group 1 ($p < 0.05$). No significant differences were found when comparing the maximal workloads of groups 2 and 3 (See Appendix A).

Table 1

Maximal Oxygen Uptake*

	Leg $\dot{V}O_{2max}$		Arm $\dot{V}O_{2max}$	
	Pre	Post	Pre	Post
Group 1 (Control)	2.80 (0.39)	2.68 (0.44)	2.03 (0.37)	1.87 (0.26)
Group 2 (Leg Only)	2.81 (0.18)	3.10** (0.16)	2.11 (0.26)	2.25 (0.29)
Group 3 (Leg & Arms)	2.90 (0.48)	3.22** (0.59)	2.03 (0.40)	2.01 (0.43)

*Mean (±SD) of $\dot{V}O_{2max}$ (L/min) values measured for leg and arm tests before and after training.

**Indicates a significant difference from control group ($p < .05$).

Note: There were no other statistically significant differences among any of the groups.

Table 2

Maximal Workloads*

	Leg kp_{max}		Arm kp_{max}	
	Pre	Post	Pre	Post
Group 1 (Control)	3.86 (0.48)	3.64 (0.56)	1.61 (0.24)	1.79 (0.22)
Group 2 (Leg Only)	3.92 (0.38)	5.50** (0.32)	1.71 (0.10)	2.17 (0.20)
Group 3 (Leg & Arms)	3.90 (0.42)	5.20** (0.76)	1.55 (0.21)	1.95 (0.33)

*Mean (±SD) of the maximal workloads kp_{max} (kp) measured for leg and arm tests before and after training.

**Indicates a significant difference from control group.

Note: There were no other statistically significant differences among any of the groups.

Heart Rate

Maximal Heart Rate

Data on maximal heart rate are presented in Table 3. The posttest maximal heart rate scores were not significantly different among any of the groups (See Appendix A).

Respiratory Exchange Ratio (RER)

Data on RER measures are listed in Table 4. The posttraining RER values were not significantly different among any of the groups (See Appendix A).

Table 3

Maximal Heart Rate*

	Leg HR_{max}		Arm HR_{max}	
	Pre	Post	Pre	Post
Group 1 (Control)	184.0 (15.0)	181.0 (12.0)	176.0 (9.0)	172.0 (10.0)
Group 2 (Leg Only)	192.0 (8.0)	188.0 (10.0)	179.0 (13.0)	180.0 (11.0)
Group 3 (Leg & Arms)	190.0 (9.0)	190.0 (5.0)	181.0 (14.0)	176.0 (9.0)

*Mean (±SD) of maximal heart rate values measured for leg and arm tests before and after training.

Note: There were no statistically significant differences among any of the groups.

Table 4

Respiratory Exchange Ratio*

	Leg RER		Arm RER	
	Pre	Post	Pre	Post
Group 1 (Control)	1.15 (0.07)	1.13 (0.05)	1.12 (0.06)	1.09 (0.06)
Group 2 (Leg Only)	1.15 (0.08)	1.08 (0.04)	1.14 (0.04)	1.10 (0.04)
Group 3 (Leg & Arms)	1.07 (0.04)	1.08 (0.03)	1.09 (0.07)	1.07 (0.03)

*Mean (±SD) of respiratory exchange ratio (RER) values measured for leg and arm tests before and after training.

Note: There were no statistically significant differences among any of the groups.

CHAPTER 5

DISCUSSION

The purpose of this study was to determine if "transfer effects" occur when the arms are isolated from involvement during leg training. Surprisingly, the results of the present study indicate that the endurance capacity of the arms was not increased for either experimental group even though the experimental design involved two-legged cycle training. These findings are in direct conflict with previous studies by Lewis et al. (1980) and Rosler et al. (1985) that demonstrated "transfer effects". No significant differences were found among the three groups in either the arm $\dot{V}O_{2max}$ levels or arm maximal workloads achieved. There were, however, clear increases in the endurance capacity of the legs. The posttraining data clearly indicates that both groups 2 and 3 made significant changes in leg $\dot{V}O_{2max}$ values and maximal workloads achieved as compared to group 1. Both the HR_{max} and RER values clearly indicated that maximal levels were attained during all of the pre- and postexercise tests. Therefore, the lack of cross transfer to the arms found in this study as compared to those of Lewis et al. (1980) and Rosler et al. (1985) were attributed to differences in the experimental design. Thus, the following section addresses the differences in experimental design of the present study compared to previous studies in an attempt to explain the differences in results.

The intensity utilized in the present study was held at 85-90% of the subject's HR_{max} throughout the duration of the 30 minute training session. Furthermore, the exercise sessions were conducted 4 days per week. Both of these characteristics of the training program equal or exceed those used in other studies. The main difference in experimental design appears to lie in the duration of training. The present study was conducted over a 4 week period, which is substantially shorter than the durations used by Lewis et al. (1980) and Rosler et al. (1985). The shorter duration used in the present study seems to account for smaller changes in the $\dot{V}O_{2max}$ values when compared with those of Lewis et al. (1980) and Rosler et al. (1985). Increases in leg and arm $\dot{V}O_{2max}$ values for group 2, was 10.3% and 6.6%, respectively, and for group 3, 11% and -1.0%, respectively. Rosler et al. (1985) reported increases in leg and arm $\dot{V}O_{2max}$ values of 13.1% and 8.5% whereas Lewis et al. (1980) reported increases in leg and arm $\dot{V}O_{2max}$ values of 16.5% and 9.0%, repectively. Clearly, the studies that have used longer training durations have recorded larger changes in $\dot{V}O_{2max}$ values. The shorter duration used in the present study was probably insufficient to cause changes in the functional capacity of the central cardiovascular system.

Another explanation for the results seen in studies that have shown "transfer effects" may be related to the unnoticed arm involvement during leg training. While most researchers recognize the importance of limiting arm use during leg training, the degree of arm involvement is often overlooked. The question arises as to how much arm involvement is too much? Secher et al. (1977) reported that an average of 36% of the total work output was performed by the arms during combined arm and leg maximal and submaximal exercise. These finding suggest that the arm involvement during leg training in the studies by Lewis et al. (1980) and Rosler et al. (1985) exceeded that of merely supporting the body weight.

Lewis et al. (1980) required his subjects to exert maximal efforts on cycle ergometers following each training session for the purpose of attaining a new maximal heart rate for the following session. Perhaps such maximal efforts conducted over an 11 week period increased the arm involvement to an extent to cause increases in the endurance capacity of the arms. Another possibility is that when the arms were added to the ongoing leg work, the total amount of muscle mass was increased to a level that caused a greater volume load on the heart which invoked central adaptations resulting in cross transfer to the arms.

Likewise, Rosler et al. (1985) reported that no particular care was taken to prevent the subjects from using their arms during the training. Rosler reported that each subject trained at the maximal power output maintainable for 30 minutes. Perhaps the extent of arm involvement was again underestimated which falsly indicated transfer effects to the arms.

Further work is needed in the area of cross adaptation. If more care is taken in the research design, the issues dealing with muscle mass involvement, central vs. perpherial adaptations, and cross transfer may be more clearly resolved. The best research design would be one that is conducted at the proper intensity (85-90% HR_{max}), freqency (4-5 day per week), and duration (10-11 weeks) while attempting to carefully isolate the arms from involvement during leg training.

LIST OF REFERENCES

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Clausen, J. P. Effect of physical training on cardiovascular adjustments to exercise in man. Physiol. Rev. 57(4):779-815, 1977.

Davies, C. T. M., and A. J. Sargeant. Effects of training on the physiological responses to one- and two-leg work. J. Appl. Physiol. 38(3):377-381, 1975.

Lewis, S. F., P. Thompson, N-H. Areskog, P. Vodak, M. Marconyak, R. Debusk, S. Mellen, and W. Haskell. Transfer effects of endurance training to exercise with untrained limbs. Eur. J. Appl. Physiol. 44:25-34, 1980.

Nagle, F. J., J. P. Richie, and M. D. Giese. $\dot{V}O_{2max}$ responses in separate and combined arm and leg air-braked ergometer exercise. Med. and Sci. in Sport. 16(6):563-566, 1984.

Rosler, H. H., K. E. Conley, H. Classen, P. Gehr, and H. Howald. Transfer effects in endurance exercise-adaptations in trained and untrained muscles. Eur. J. Appl. Physiol. 54:355-362, 1985.

Saltin, B., K. Nazar, D. L. Costill, E. Stein, E. Jansson, B. Essen, and P. D. Gollnick. The nature of the training responses; peripheral and central adaptations to one-legged exercise. Acta. Physiol. Scand. 96:289-305, 1976.

Sawka, M. N, M. E. Foley, N. A. Pimental, M. M. Toner, and K. B. Pandolf. Determination of maximal aerobic power during upper-body exercise. J. Appl. Physiol. 54(1):113-117, 1983.

Secher, N. H., N. Ruberg-Larsen, R. A. Binkhorst, and F. Bonde-Petersen. Maximal oxygen uptake during arm cranking and combined arm plus leg exercise. J. Appl. Physiol. 36(5):515-518, 1974.

Secher, N. H., J. P. Clausen, K. Klausen, I. Noer, and J. Trap-Jensen. Central and regional circulatory effects of adding arm exercise to leg exercise. Acta. Physiol. Scand. 100:288-297, 1977.

APPENDICES

APPENDIX A

GROUP COMPARISONS OF THE DIFFERENCES BETWEEN THE PRE- AND POSTTEST MEASURES

Table A-1

Group Comparisons of Leg $\dot{V}O_{2max}$ Using the General Linear Models Procedure

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.77596492	0.38798246	12.76	0.0006
Error	15	0.45619619	0.03041308		
Corrected Total	17	1.23216111			

Table A-2

Group Comparison of Leg $\dot{V}O_{2max}$ Using the Bonferroni (Dunn) T Test

Group Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit
3 - 2	-0.2638	0.0207	0.3051
3 - 1	0.1618	0.4369	0.7119***
2 - 1	0.1548	0.4162	0.6775***

***Indicates comparisons significant at the 0.05 level.

Note: Alpha = 0.05; Confidence = 0.95; df = 15; MSE = .0304131; Critical Value of T = 2.69374.

Table A-3

Group Comparisons of Arm $\dot{V}O_{2max}$ Using the General Linear Models Procedure

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.28464111	0.14232056	2.07	0.1604
Error	15	1.02985333	0.06865689		
Corrected Total	17	1.31449444			

Table A-4

Group Comparison of Arm $\dot{V}O_{2max}$ Using the Bonferroni (Dunn) T Test

Group Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit
2 - 3	-0.277	0.151	0.578
2 - 1	-0.096	0.297	0.689
3 - 1	-0.267	0.146	0.559

Note: Alpha = 0.05; Confidence = 0.95; df = 15; MSE = .0686569; Critical Value of T = 2.69374.

Table A-5

Group Comparisons of Leg Maximal Workloads (kp) Using the General Linear Models Procedure

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	12.13253968	6.06626984	26.48	0.0001
Error	15	3.43690476	0.22912698		
Corrected Total	17	15.56944444			

Table A-6

Group Comparison of Leg Maximal Workloads (kp) Using the Bonferroni (Dunn) T Test

Group Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit
2 - 3	-0.497	0.283	1.064
2 - 1	1.080	1.798	2.515***
3 - 1	0.759	1.514	2.269***

***Indicates comparisons significant at the 0.05 level.

Note: Alpha = 0.05; Confidence = 0.95; df = 15; MSE = 0.229127; Critical Value of T = 2.69374.

Table A-7

Group Comparisons of Arm Maximal Workloads (kp) Using the General Linear Models Procedure

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.28363095	0.14181548	4.56	0.0283
Error	15	0.46636905	0.03109127		
Corrected Total	17	0.75000000			

Table A-8

Group Comparison of Arm Maximal Workloads (kp) Using the Bonferroni (Dunn) T Test

Group Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit
2 - 3	-0.2293	0.0583	0.3459
2 - 1	0.0155	0.2798	0.5440***
3 - 1	-0.0567	0.2214	0.4995

***Indicates comparisons significant at the 0.05 level.

Note: Alpha = 0.05; Confidence = 0.95; df = 15; MSE = .0310913; Critical Value of T = 2.69374.

Table A-9

Group Comparisons of Leg Maximal Heart Rates Using the General Linear Models Procedure

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	32.53015873	16.26507937	0.56	0.5828
Error	15	435.74761905	29.04984127		
Corrected Total	17	468.27777778			

Table A-10

Group Comparison of Leg Maximal Heart Rates Using the Bonferroni (Dunn) T Test

Group Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit
3 - 1	-6.330	2.171	10.673
3 - 2	-5.358	3.433	12.225
1 - 2	-6.816	1.262	9.339

Note: Alpha = 0.05; Confidence = 0.95; df = 15; MSE = 29.04984; Critical Value of T = 2.69374.

Table A-11

Group Comparisons of Arm Maximal Heart Rates Using the General Linear Models Procedure

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	133.93015873	66.96507937	0.96	0.4057
Error	15	1047.84761905	69.85650794		
Corrected Total	17	1181.77777778			

Table A-12

Group Comparison of Arm Maximal Heart Rates Using the Bonferroni (Dunn) T Test

Group Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit
2 - 1	-7.431	5.095	17.621
2 - 3	-7.166	6.467	20.100
1 - 3	-11.812	1.371	14.554

Note: Alpha = 0.05; Confidence = 0.95; df = 15; MSE = 69.85651; Critical Value of T = 2.69374.

Table A-13

Group Comparisons of Leg Respiratory Exchange Ratio (RER)
Using the General Linear Models Procedure

Source	DF	Sum of Squares	Mean Square	F Value	Pr ¶ F
Model	2	0.01999429	0.00999714	3.36	0.0622
Error	15	0.04460571	0.00297371		
Corrected Total	17	0.06460000			

Table A-14

Group Comparison of Leg Respiratory Exchange Ratio (RER)
Using the Bonferroni (Dunn) T Test

Group Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit
3 - 1	-0.0534	0.0326	0.1186
3 - 2	-0.0049	0.0840	0.1729
1 - 2	-0.0303	0.0514	0.1332

Note: Alpha = 0.05; Confidence = 0.95; df = 15; MSE = .0029737; Critical Value of T = 2.69374.

Table A-15

Group Comparisons of Arm Respiratory Exchange Ratio (RER)
Using the General Linear Models Procedure

Source	DF	Sum of Squares	Mean Square	F Value	Pr ¶ F
Model	2	0.00051667	0.00025833	0.14	0.8724
Error	15	0.02813333	0.00187556		
Corrected Total	17	0.02865000			

Table A-16

Group Comparison of Arm Respiratory Exchange Ratio (RER)
Using the Bonferroni (Dunn) T Test

Group Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit
3 - 1	-0.0583	0.0100	0.0783
3 - 2	-0.0573	0.0133	0.0840
1 - 2	-0.0616	0.0033	0.0682

Note: Alpha = 0.05; Confidence = 0.95; df = 15; MSE = .0018756; Critical Value of T = 2.69374.

APPENDIX B

HEALTH SCREENING AND CONSENT FORM

SCREENING FOR HEALTH-RELATED FITNESS PARTICIPATION

Instructions. Check yes or no by each of the following items:

___Yes ___No Presently have, or have had, cardiovascular disease (e.g., heart problems).

___Yes ___No Have pains or pressure in the left or midchest area, left neck, shoulder, or arm at rest or in response to exertion.

___Yes ___No Often feel faint or have spells of dizziness.

___Yes ___No Experience extreme breathlessness after mild exertion.

___Yes ___No Have high blood pressure.

___Yes ___No Have high cholesterol.

___Yes ___No Smoke more than a pack of cigarettes a day.

___Yes ___No Am over 60 years of age and not accustomed to vigorous exercise.

___Yes ___No Have bone or joint problems that would interfere with exercise.

___Yes ___No Have two or more of the following:

a. Family history of premature coronary artery disease.
b. Obesity.
c. Sedentary life style.
d. Type A behavior with stressful occupation and/or lifestyle.
e. Diabetes.

___Yes ___No Have a medical condition not mentioned here which might need special attention in an exercise program.

****

If you've checked yes on one or more items, you need medical permission to participate in this study. If you've checked none of the items, you can participate in the experiment with minimum risk. If there is any question in your mind that exercise might cause any kind of problems, see your physician before engaging in the study.

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*Adapted from, Exercise and your heart. U.S. Dept. Health and Human Services, 1981; and Guidelines for Graded Exercise Testing and Exercise Prescription. American College of Sports Medicine, 1980.

CONSENT FORM

I understand that the outlined study will include 16 exercise sessions conducted over a four week training period. I will attend an introductory conference meeting prior to two maximal aerobic exercise tests, as well as a follow-up conference meeting after two final maximal aerobic exercise tests.

In order to determine my maximal aerobic capcity, I hereby consent, voluntarly, to maximal exercise tests on both an arm ergometer and a leg ergometer. The tests will be taken before and after the four week endurance training program. I shall perform a graded exercise test by either cranking an arm ergometer or by riding a cycle ergometer. The exercise will begin at a low level and be advanced in stages. The test may be stopped at any time because of objective signs of fatigue or when a desired hear rate is reached. I understand that I may stop the test at any time because of my feelings of fatigue or discomfort, or for any other personal reason.

I understand that the risks of the testing procedure may include disorders of heart beats, abnormal blood pressure response, and, very rarely, a heart attack.

I understand that the testing does not entirely eliminate the risk of the proposed endurance exercise program. I will be given an individual target heart rate for the exercise sessions. I elect to participate in the exercise program willingly and at my own risk.

I understand that information from this study may be used for research publications. I understand that my identity will not be revealed and that I may withdraw my consent at any time.

The requirements for participation in this study have been fully explained to me. I am aware of the fact that I may withdraw from the study at any time without penalty. There will be no coercion for me to continue in the study.

____
SIGNED

____
WITNESS

____
DATE

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VITA

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