

THE CROSS-TRAINING EFFECT BETWEEN SWIMMING AND RUNNING

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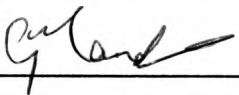
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DECLARATION

I, Georgia Mandilas declare that this research report is my own work, except to the extent indicated in the acknowledgements. It is being submitted for the degree of Master in Science in Medicine in the field of Exercise Science, University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at this or any other University.

G. MANDILAS



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ABSTRACT

This investigation examined the cross-training effect of swim training on middle distance running performance. Eight, healthy, untrained subjects (mean age $\pm$ SD = 24.63 $\pm$ 2.77 yrs) participated in a 12 week swim training program. Before and immediately following the training period, measurements were made of: maximal oxygen consumption ($\dot{V}O_2$ max.) (treadmill); anaerobic capacity (Wingate test); knee and shoulder muscle strength (isokinetic dynamometer); 100m and 200m swim time-trials; and 400m and 800m run time-trials.

$\dot{V}O_2$ max. increased from a mean of 42.06 $\pm$ 5.1 ml/kg/min. to 45.39 $\pm$ 5.05 ml/kg/min. (8.13% ; $p < 0.005$). The 100m, 200m swim times and the 400m, 800m run times improved significantly in response to the swimming training ($p < 0.0001$).

Dynamometry showed significant increases in power and work during knee flexion at an angular velocity of 60 $^\circ$ /sec; knee extension at 245 $^\circ$ /sec; and during shoulder flexion and extension at 195 and 245 $^\circ$ /sec. The Wingate test however, did not show any changes after the training period.

A cross-training effect by swim training on running performance was attained among the untrained, non-competitive swimmers of this study. While mode of activity was non-specific, a training response was attained by keeping the intensity and volume of the swim training specific to middle distance run training.

CHAPTER 1

LITERATURE REVIEW

1.1) INTRODUCTION

Crosstraining has been defined as deriving benefits in the performance of one mode of activity, through training done in another mode of activity (Claussen et al, 1973; Saltin et al, 1976). One has to expand this definition when considering the disciplines of biathlons and triathlons. Crosstraining in the context of these activities, becomes a question of establishing the ideal amounts of training in each of the two or three sport modes for optimising performance and minimising the occurrence of overuse injuries (O'Toole et al, 1989).

1.2) PHYSIOLOGICAL RESPONSES COMPARED IN SWIMMING AND RUNNING

Differences in some physiological responses during swimming as compared to running, may explain the existence or absence of a cross-training effect between swimming and running. Thus, this literature review will begin by briefly investigating this topic.

1.2.1 Physiological responses during submaximal work

During submaximal work oxygen consumption, cardiac output, stroke volume, heart rate, minute ventilation, and arterio-venous oxygen difference were similar in swimming and in running (Holmer et al, 1972a, 1974a). Only mean blood pressure was constantly higher during submaximal swimming when compared to submaximal running.

On the basis of these findings, Holmer et al (1974a) concluded that the cardiorespiratory system responded to increased workloads in a similar pattern during both swimming and running.

Reilly et al (1990) also reported that central cardiovascular responses to a stepwise increment in swimming intensity were similar to observations during land ergometry.

This occurred in spite of dissimilar posture, respiratory mechanics, external hydrostatic pressure, and heat dissipation between the two sport modes.

Contrary to the above, Magel (1971) found submaximal heart rate to be lower during swimming than during running. This finding suggested that the use of a heart rate- $\dot{V}O_2$ relation determined on dry land exercises was invalid for prediction of energy expenditure in water.

1.2.2 Physiological responses during maximal work

During maximal work though, oxygen consumption; cardiac output; heart rate; ventilation and arterio-venous oxygen difference were consistently lower in swimming (Holmer et al, 1972a, 1974a; Magel & Foglia, 1975; Gergley et al, 1984; Svedenhag & Seger, 1992).

Some research however, has shown maximal oxygen consumption ($\dot{V}O_2$ max.) during swimming to be similar to $\dot{V}O_2$ max. during running. This will be debated further in an ensuing section of this literature review.

Maximal swimming stroke volume has been found to be similar to maximal running stroke volume. Also, blood lactate and oxygen extraction values from circulating blood in exercising leg have been found to be the same for maximal swimming and running (Holmer et al, 1974a).

Furthermore, P_{aO_2} , P_{aCO_2} , and oxygen saturation during maximal swimming and running have been found to be approximately the same. Also, oxygen capacity and oxygen content of arterial blood were similar during both swimming and running (Holmer et al, 1974a).

In addition, Holmer et al (1974a) found that calculated dead space was lower and alveolar ventilation was higher during both submaximal and maximal swimming when compared to running. On the basis of the above findings, Holmer et al (1974a) concluded that during maximal swimming gas exchange is sufficient to maintain an oxygenation of arterial blood similar to that observed during maximal running.

Maximal respiratory exchange ratios (R) values were the same for running and swimming. The R value at a given submaximal workload was lower during running than during swimming. (Holmer et al, 1974a).

One needs to consider though, that only five subjects were used in the Holmer et al (1974a) study. In addition, the subjects entered the study with a higher degree of prior running training compared to swimming training. This may have influenced the individual hemodynamic responses to maximal work.

1.2.3 Reasons for the differences in physiological responses during swimming and running

According to the research of Stenberg et al (1967) and Gergley et al (1984), a reason for the differences in maximal $\dot{V}O_2$; cardiac output; and heart rate between swimming and running may be the smaller working muscle mass involved in swimming as compared to running.

Svedenhag et al (1992) suggested that the lower maximal heart rate found in swimming may be due to an increase in heart volumes that occurred in swimming when compared to running.

The smaller muscle mass and lowered thermoregulatory demands for the skin circulation in swimming have been cited as causes of a less dilated vascular bed in swimming, which in turn would cause an increase in peripheral resistance. This could explain the higher mean blood pressure exhibited during submaximal and maximal swimming, since cardiac output remains unchanged or is lowered (Holmer et al, 1974a).

Differences in running and swimming $\dot{V}O_2$ max. values have also been explained in terms of differences in perfusion pressure in working leg muscles when comparing swimming and running (Holmer et al, 1972a, 1974a). The lower perfusion during swimming may result in a reduced blood flow and oxygen transport, and thus a lower $\dot{V}O_2$ max. (Holmer, 1972a)

Also, Svedenhag et al (1992) states that a longer muscular contraction duration during maximal swimming could limit muscle blood flow and thus result in a lower cardiac output and consequently a lower $\dot{V}O_2$ max.

Bonen et al (1980) have suggested that the differences in the oxidative capacities of the muscles employed during swimming and running may constitute an additional reason for the difference between treadmill and swimming $\dot{V}O_2$ max.

1.3) Differences in muscle morphology between swimmers and runners

Peripheral adaptations to training have been shown to be specific to the type of training program utilised, and to be as essential for cardiovascular performance during exercise as any central factors (Saltin et al, 1976). The training principle of specificity is based upon the data presented by Saltin et al in 1976. It is relevant therefore, to discuss the differences between swimmers and runners at the muscular level when investigating cross-training between swimming and running.

1.3.1 Muscle fiber types

Different proportions of fast and slow twitch fibers in a muscle dictate whether the muscle has predominantly fast or slow contractile speeds, and determine its predominant means of producing energy (Reilly et al, 1990).

Studies have also shown that the recruitment pattern during exercise of increasing intensity is: Type I > Type IIa > Type IIb; and that moderate intensity exercise can be used to train Type II fibers- provided the duration is sufficient to deplete glycogen in the Type I fibers that are initially used (Reilly et al, 1990).

Furthermore, high intensity exercise seems to recruit both Type I and Type II fibers, with Type II fibers experiencing glycogen depletion more rapidly than Type I fibers (Saltin et al, 1976; Reilly et al, 1990).

1.3.2 Muscle fiber type proportions in swimming and running

When comparing swimming and running, Nygaard and Nielsen (1978) reported 40% Type I; 41% Type IIa; and 19% Type IIb fibers in swimmers.

Reilly et al (1990) cites the study of Mero et al (1983), who found that elite run sprinters had 66.2% of Type II fibers.

Interestingly, 28% of the fast twitch fibers were Type IIb and nearly 40% were Type IIa.

On the other hand, the research of Costill et al (1976) indicates that middle distance runners have an even distribution of fast and slow twitch muscle fibers. More importantly, Maglischo (1982) suggested that sprint swimmers should have less Type I fibres than sprint runners, because the duration of sprint swims is longer. Distance swimmers however, should have more Type IIa fibres than distance runners. The swimmers that Maglischo investigated had 30- 68% of Type I muscle fibers.

The above-mentioned research alludes to the specificity of swimming and running training adaptations on the morphology of muscle, yet the large range of values reported in the literature make it difficult to draw any conclusions as to the specificity of muscle morphology for each sport mode.

1.3.3 Muscle morphology and the concept of cross-training

Although no conclusions can be drawn from the above discussions, four pertinent issues arise with regard to cross-training and muscle morphology:

a) Since both Type I and Type II fibers are involved in high intensity, middle-distance swimming and running; muscle morphology may be a factor that could be utilised to obtain a cross-training effect between these two activities. For example, if training in swimming is of a sufficient intensity and duration; and produces a muscle contraction speed to recruit similar proportions of Type I and Type II fibers as those recruited in running- then a cross-training effect between swimming and running may be exhibited. The cross-training effect though, might depend on the number of muscle fibers common to both swimming and running actions.

b) The reported proportion of Type IIa muscle fibers in swimmers and the shorter middle distance running events are similar (Nygaard et al, 1978; Reilly et al, 1990). Thus, a cross-training effect between swimming and shorter middle distance running might be attained if this particular fiber type is recruited during training.

c) Different distances/ events in swimming and running recruit different muscle fiber types. For example, Type IIa fibers would be of more importance to a 200m and 400m runner than to a 100m sprinter (Reilly et al, 1990).

Therefore, improvement or maintenance of 200 or 400m run performances may not occur if swim training involves long-distances that primarily recruit Type I fibers. A cross-training effect may however be seen if swim training involves short-distances and medium to high intensity work-bouts- (since, this type of training would recruit a high proportion of Type IIa fibers).

d) An even distribution of Type I and Type II muscle fibers, (as occurs in runners of middle-distance events), may allow for the possibility of a cross-training effect between middle-distance running and equivalent swimming.

1.4) EFFECTS OF LONG-DISTANCE TYPE TRAINING IN ONE MODE OF ACTIVITY ON THE PERFORMANCE IN ANOTHER MODE OF ACTIVITY

Most of the studies in the field of crosstraining have investigated long-distance duathlons and triathlons, or the effects of long-distance type training in one mode of activity on the performance of another mode of activity.

More specifically, many studies have trained a single group of subjects in one mode of exercise and then tested for training effects in two or more exercise modes (Clausen et al, 1970, 1973; McArdle et al, 1971, 1978; Davies & Sargeant, 1975; Rasmussen et al, 1975; Saltin et al, 1976; Stromme et al, 1977; Magel et al, 1978; Wilmore et al, 1980; Gwinup, 1985).

The evidence of these particular studies strongly suggest a large, specific, peripheral component to training; and support the view that training adaptations are specific to the mode of training.

In contrast however, some studies involving endurance-type training programs, do show evidence of a non-specific cross-training effect.

Pollock et al (1975) compared the effects of a running; walking; and cycling, endurance-type training programs over 20 weeks on treadmill; bicycle ergometer and walking VO_2 max. The sedentary, middle-aged subjects of this study trained at 85 - 90% of their maximal heart rate, and training intensity was kept similar across all three training regimes. At the end of the training period a cross-training effect was evident, since the walking and running training groups improved significantly in the cycling VO_2 max.

Their cycling VO_2 max. values however, were lower than those of their running and walking tests. In contrast, the cycle-trained group performed equally well on all three modes of testing after 20 weeks of bicycle training.

The researchers concluded that training improvements were independent of mode of training when frequency, duration and intensity of training were held constant.

Similarly, Pechar et al (1974) investigated the specificity of cardiorespiratory adaptation to bicycle and treadmill training. These researchers also found that changes in VO_2 max. were dependent on both the mode of training and the method of measuring VO_2 max. More specifically, Pechar et al (1974) showed that after 8 weeks of treadmill training, the improvement in VO_2 max. was independent of the method of VO_2 max. measurement. However, after bicycle ergometer (BE) training, the improvement in BE VO_2 max. was significantly greater than the increase in treadmill VO_2 max. Thus, these researchers concluded that run training produces a general VO_2 max. improvement, whereas bicycle training produces a specific training effect.

In analysing the previous two studies, one needs to consider that leg strength and endurance have been shown to play an important role when performing a cycle VO_2 max. test (Faulkner et al, 1971). These two physical fitness components (i.e. local muscle strength and endurance), may thus also play an influential role with respect to attaining a cross-training effect between two modes of activity.

Loy et al (1995) when reviewing dissimilar modes of training, stated that a cross-training approach will involve some central adaptation transfer, particularly for beginners or those with lower levels of aerobic fitness.

Loy et al though also stated that cross-training effects do not exceed those induced by activity-specific training, especially at higher levels of fitness.

Roberts and Morgan (1971) compared the training effects of endurance running, cycling and swimming; and found that the running training produced the greatest improvement. These researchers however, used specific heart rates as a measure of training intensity. Therefore, training loads between groups may not have been equal due to the presence of wide individual variations in maximal heart rate (Pollock et al, 1975). The use of percentage of maximal heart rate as a measure of training intensity, may have been a more valid approach.

1.4.1 Training specificity and multiple mode athletes

Furthermore, certain cross-sectional studies on "multiple mode" athletes (eg. triathletes) support the concept of training specificity.

Kohrt et al (1987a) for example, tested the tethered swimming, ergometer cycling and treadmill running $\dot{V}O_2$ max. of 13 male triathletes (of varying ability levels), prior and following a 6 week period of training. These researchers found that treadmill $\dot{V}O_2$ max values were higher than those of cycling, which in turn were higher than swimming $\dot{V}O_2$ max values.

Also, the triathletes' VO_2 max values in each different sport mode were higher than recreational athletes in the particular sport mode; but were lower than values of elite athletes in each individual sport mode.

Kohrt et al (1987a) thus suggested that if the triathletes had experienced a general training response, similar VO_2 max values might have been expected in all three sport modes. Therefore, it was concluded that the results of this study indicated a specific training response.

This conclusion was confirmed by further research by Kohrt et al (1989), when investigating fourteen triathletes over a 10 month period, to monitor adaptations to training for a triathlon.

1.4.2 Methodological problems in the research area of training specificity and cross-training

The two preceding studies (Kohrt et al, 1987a and 1989) however, allude to certain methodological problems in the research area of training specificity and cross-training:

1.4.2.1) The triathletes in the studies of Kohrt et al (1987a and 1989) were not tested in an untrained state.

Thus it is difficult to accurately ascertain how these triathletes adapted to the research training period, since there already existed a prior training effect.

1.4.2.2) Differences in training volume; total energy cost of training regimen; and relative training intensity between subject training groups, may also influence results and help explain contradictory research (Pollock et al, 1975; Lieber et al, 1989).

In this regard, Kohrt et al (1989) mentioned that the mean weekly training volumes (for each sport mode) reported by the triathletes of his study, were lower than those normally seen in athletes training only in one sport mode. Therefore, it may have been the case that the triathletes did not achieve as high a cycling or swimming VO_2 max relative to running when compared to trained cyclists or swimmers because of differences in training volumes.

Pechar et al (1974) in comparing the effects of treadmill and cycle ergometer training on treadmill and cycle ergometer VO_2 max. , also made mention of the methodological problem of training intensity.

These researchers pointed out that although 85% of maximal heart rate was used to equate work intensity for both training groups, the general cardiorespiratory response was less during cycling than during treadmill training. This is due to the lower stroke volume that occurs during cycling (Faulkner et al, 1971). This dissimilarity between the run and cycle trained groups may have resulted in the two groups training at different intensities.

1.4.3 Training mode and $\dot{V}O_2$ max test specificity

Many of the studies cited above have used $\dot{V}O_2$ max as the criterion measure of change. Three considerations must thus be addressed:

1.4.3.1 Training mode and mode of $\dot{V}O_2$ max test

Most research evidence shows higher $\dot{V}O_2$ max values in the specific activity an athlete is trained in, when compared to other sport activities (Faulkner et al, 1967, 1971; Holmer et al, 1972b, 1974a; Stromme et al, 1977; Gergley et al, 1984; Kohrt et al, 1987a). The research of Hermansen and Saltin (1969); and Hermansen et al (1970) have also confirmed $\dot{V}O_2$ max. specificity to the mode of testing.

Findings of the above studies indicate that peripheral factors and the recruitment of specifically trained muscles, play an important role in the attainment of a high $\dot{V}O_2$ max value. This is supported by Magel et al (1978) who showed that improvement in peak $\dot{V}O_2$ with arm-cranking training was entirely due to an increased (a-v) $\dot{O}_2$ difference.

Thus, it seems that training in a particular activity elicits the recruitment of specific muscle groups, fibers and metabolic processes; and unless these are totally involved during a $\dot{V}O_2$ max test, attainment of an optimally high $\dot{V}O_2$ max will not be achieved.

If $\dot{V}O_2$ max. testing is mode specific, it may be a factor contributing to the variable results of cross-training studies. For example, using only a treadmill $\dot{V}O_2$ max. test to measure the effect of a running training program on swim performance, may "mask" any cross-training effects.

However, research exists that contradicts the training specificity for $\dot{V}O_2$ max. testing:

Magel and Faulkner (1967); and Dixon and Faulkner (1971) did not observe any differences in $\dot{V}O_2$ max. during treadmill running and tethered swimming.

Astrand and Saltin (1961), found higher $\dot{V}O_2$ max values in uphill running on a treadmill than during skiing, when investigating cross-country skiers.

Carey et al (1974), measured aerobic capacity in 5 Harvard Varsity crew members and found the same $\dot{V}O_2$ max values during rowing and uphill treadmill running.

Lieber (1989), formulated the following hypothesis as a result of his research on the effects of run-training and swim-training on treadmill $\dot{V}O_2$ max:

If two subject groups are trained in different exercise modes at nearly similar absolute exercise intensity that is sufficient to cause central circulation adaptatation; and then are tested in a mode that elicits sufficient central circulatory demands, training specificity for $\dot{V}O_2$ max. will not be demonstrated.

Holmer et al (1974b) further state that it is the intensity and specificity of swimming training that should determine the closeness of a trained individual's swimming and running $\dot{V}O_2$ max values.

1.4.3.2 Reasons for contradictory evidence in the field of specificity of VO_2 max testing

Researchers have cited some reasons for contradictory evidence in the field of specificity of VO_2 max. testing:

i) VO_2 max measurement protocol

The influence of different swimming and running VO_2 max. test procedures on research results cannot be ignored- i.e. VO_2 max. is specific to the exercise protocol employed (Holmer 1972b, 1974b; Pechar et al, 1974; Svedenhag et al, 1992). Subjects need to be exerted to similar relative workloads in the different sport-specific VO_2 max tests. For example, as mentioned by Stromme et al (1977), skiing on a flat, horizontal track will not exert a subject to a similar relative workload as that for running on an incline.

Similarly, Bishop et al (1989) found that two athletes in their study with relatively high oxygen consumptions, were able to achieve relatively high oxygen consumptions for both swimming and running. These researchers suggested that this finding indicates the feasibility of achieving the same exercise intensity (or relative workload) in water as on land.

Furthermore, high motivation and the ability to judge exertion from previous workouts were cited by these researchers as key factors in achieving the same exercise intensities and metabolic rates in water as on land.

In addition, the type of ergometer used in the $\dot{V}O_2$ max test may influence the result attained. For example, a rowing ergometer may not simulate the exact power mechanics that occur in "free" or actual rowing (Stromme et al, 1977).

ii) Subject level of fitness

Astrand et al (1961); Ekblom and Hermansen (1968a); McArdle et al (1971); Holmer et al (1972a, 1974a); Saltin et al (1976), have all shown that swimming $\dot{V}O_2$ max values are lower than running $\dot{V}O_2$ max values among recreational swimmers.

This finding however, is not conclusively evident among trained and elite swimmers. Faulkner (1967); Magel et al (1967, 1975); Dixon et al (1971), found no difference between the running and swimming $\dot{V}O_2$ max values of elite swimmers. In contrast however, Holmer et al (1974b) showed that even elite swimmers attain a slightly lower $\dot{V}O_2$ max. during swimming as compared to during running.

It must be noted however, that the study of Holmer investigated middle and long distance swimmers; while the research of Magel et al (1967) was concerned with elite, sprint swimmers.

Differences between running and swimming VO_2 max values, seem smaller among elite swimmers when compared to less trained or recreational swimmers (Holmer, 1972a; Magel et al, 1975). The inability of recreational swimmers to maintain a high venous return during swimming, (probably due to limited blood flow through the muscles of the arms, shoulders and chest), may be an explanation for this finding (Magel et al, 1975). This explanation is supported by Dixon et al (1971) who showed that the lower VO_2 max. of recreational swimmers was due completely to a lower cardiac output.

Another explanation involves the muscle mass used and the patterns of muscle recruitment. Clarys (1985) found that top swimmers showed a greater use of the trunkal muscles, including gluteus maximus as compared to recreational swimmers. This utilization of a greater muscle mass may be a factor allowing top swimmers to attain a higher VO_2 max. in the water and thus reducing the difference between their running and swimming VO_2 max.

Research has also shown that non-trained individuals achieve a higher $\dot{V}O_2$ max during running than during cycling and swimming (McArdle and Magel, 1970; Dixon et al, 1971; Holmer 1972a; Pechar et al, 1974; Magel et al, 1975).

iii) Training effect prior to testing

Magel et al (1967), when investigating highly trained swimmers, found higher $\dot{V}O_2$ max. values during free swimming than during running. This finding was ascribed to the influence of the long period of swimming training between $\dot{V}O_2$ max. sessions. The research of McArdle et al (1970) and Holmer et al (1972b) also support the concept that differences in $\dot{V}O_2$ max. values when comparing different exercise modes, may be influenced by the subject's prior experience with the particular form of exercise.

1.4.3.3 Changes in performance versus changes in $\dot{V}O_2$ max.

A training program may cause changes in performance, without a concurrent increase in $\dot{V}O_2$ max values (Kohrt et al, 1989; O'Toole et al, 1989; Costill et al, 1991). This may be particularly applicable to short-distance (interval type) training and activities, that primarily utilise oxygen-independent energy pathways.

This notion is supported by Kohrt et al (1987a), who showed that $\dot{V}O_2$ max. is a good predictor of endurance running or cycling (not swimming) performance, only when a heterogeneous subject group is investigated.

1.4.3.4 The relevance of $\dot{V}O_2$ max.

This study will utilise a middle-distance training protocol. Therefore, the relevance of $\dot{V}O_2$ max may not be as significant as it would be for a long-distance (endurance) training protocol.

Montpetit et al (1981) and Bishop et al (1989), showed a linear relationship between swimming $\dot{V}O_2$ peak and treadmill $\dot{V}O_2$ peak. This may be relevant to the present study, since a) an individual with a high (or low) treadmill $\dot{V}O_2$ max. should have a high (or low) swimming $\dot{V}O_2$ max; and b) a change in treadmill $\dot{V}O_2$ max. following swimming training, would imply a change in swimming $\dot{V}O_2$ max. in the same direction as that of the treadmill $\dot{V}O_2$ max.

1.5) THE EFFECTS OF SHORT-DISTANCE (INTERVAL) TYPE TRAINING IN ONE MODE OF ACTIVITY ON PERFORMANCE IN ANOTHER MODE OF ACTIVITY

There seems a lack of research evidence when one examines the literature on the effect of short-distance (interval) type training in one mode of activity on performance in another mode of activity.

Magel et al (1975) investigated the effect of an interval swim training program on college, recreational swimmers during treadmill running and tethered swimming. These researchers found that after 10 weeks of swim training, the experimental group demonstrated significant increases in swimming $\dot{V}O_2$ max.; maximal ventilation; maximal swim period. No significant improvement, however was noted in treadmill $\dot{V}O_2$ max. These findings support the specificity of $\dot{V}O_2$ max. and associated responses to interval swim training.

In the study by Magel et al (1975) though, maximum treadmill run time increased after the 10 weeks of swim training. This finding supports the concept that training in one mode of activity can improve performance in another mode of activity, without a concomitant increase in $\dot{V}O_2$ max.

Subsequent research by Magel et al (1978), confirmed their previous results regarding the specificity of adaptations to arm training. The research assessed the effect of 10 weeks of interval arm training for 20 min/day, 3 days/wk, on arm ergometer and treadmill running $\dot{V}O_2$ max. and related responses. Training intensities were set at 85% of each subject's maximal heart rate as determined in the initial arm ergometry test.

Following the arm training, peak $\dot{V}O_2$ values for arm ergometry improved while treadmill $\dot{V}O_2$ max. values remained unchanged. These findings support the importance of peripheral factors in determining the metabolic adaptation to specific exercise training.

These researchers proposed several possible mechanisms in attempting to explain the improvement in aerobic capacity following arm training: a) increased maximal cardiac output; b) more effective distribution of the cardiac output to active muscles; c) improved oxygen utilization by the trained muscles; and d) a combination of improved circulation and enhanced cellular capacity for aerobic metabolism.

However, Magel et al (1978) found an increase in max (a-v) $\dot{O}_2$ diff. without a change in maximal cardiac output following arm training.

This indicated that the improvement in aerobic capacity was dependent more on cellular metabolic capacity.

On this basis, Magel et al opted for an integrated view-point when explaining improvement in aerobic capacity with specific forms of training. More specifically, these researchers stated that the improvement in aerobic capacity probably depends upon a balance between the size of the muscle mass exercised and the degree to which the training loads the central circulatory system.

The research data of Gergley et al (1984) also support the specificity of training adaptations, and suggest that local (peripheral) adaptations contribute significantly to the improvement in peak oxygen consumption. These researchers evaluated the effect of a 10 week, interval, arm-training program on the peak $\dot{V}O_2$ of tethered swimming; swim-bench swimming and treadmill running. In this study, twenty five, recreational swimmers were divided into control; swim trained (S-trained); and swim-bench pulley trained (SB-trained) groups. The SB-trained group showed the greatest improvement in post-training peak $\dot{V}O_2$ using the swim-bench test, followed by the tethered swim test.

The S-trained group showed similar increases in swim-bench and tethered swimming peak $\dot{V}O_2$. Both training groups though, showed no change in treadmill peak $\dot{V}O_2$.

These findings indicate that arm training elicits a specific training response. One must consider however, that only running peak $\dot{V}O_2$ was measured in the study by Gergley et al. An improvement in other indicators of running performance may have occurred without a concomitant increase in running peak $\dot{V}O_2$ especially since an interval, short-distance type training program was utilised by Gergley et al.

Furthermore, Clausen et al (1973) examined the central and peripheral (local) circulatory changes after 5 weeks of interval- type arm training as compared to interval- type, bicycle ergometer training. This study showed specific adaptations to both arm and leg training.

Clausen et al suggested that their findings reflect the greater potential of arm muscles for local improvement; and that central circulatory changes occur in proportion to the amount of muscle mass used during the training. These researchers concluded that cardiovascular adjustments are different during exercise with small muscle groups as compared to during exercise with large muscle groups.

1.6) RESEARCH EVIDENCE ALLUDING TO A CROSS- TRAINING EFFECT

Some research studies have shown evidence of cross-training effects. Korht et al (1987b), investigated a group of triathletes and reduced their cycling and swim training by 60% and 72% respectively. At the end of a three month period, running and cycling VO_2 max had decreased, yet swim VO_2 max had been maintained. The researchers of this study used the concept of cross-training as one possible explanation for their results- i.e. that swimming capacity could be maintained by non-specific training (running). The alternate explanation given by the researchers was that a smaller volume of training is necessary to maintain swim VO_2 max than that required to maintain running and cycling VO_2 max.

A study by Lieber et al (1989) controlled for the variable effect of absolute training volume and intensity between subject training groups and showed evidence of a cross-training effect. This research involved 37 sedentary males, randomly assigned to 3 groups: run-training, swim-training and a control group. A treadmill VO_2 max was performed by all subjects prior to and following an 11 week, long-distance (endurance)-type training program.

Both training groups were set the same training intensity:- a heart rate that corresponded to 75% of each individual's maximal heart rate (as obtained during the initial $\dot{V}O_2$ max test). Therefore, training groups in the different exercise modes, trained at the same relative intensity and absolute volume.

Furthermore, the target heart rate for the swim training group was adjusted downward by 6 bt/min. This adjustment was based on the observation that face immersion with regular ventilation in water decreases the heart rate (Magel et al, 1982).

These researchers found no difference in the increase in treadmill $\dot{V}O_2$ max between the runners and swimmers. It was thus concluded that when training intensities and volumes are kept similar between training groups of the different exercise modes, there exists support for the concept of cross-training.

The results of this study suggest that the training response may not only be influenced by training in different modes of activity; but also by training intensity, training volume, fitness levels, and muscle mass involved during training.

1.6.1 The interplay between peripheral and central adaptations: an explanation for a cross-training effect

In discussing research findings, Lieber et al (1989) proposed a unique way of viewing training specificity. These researchers suggested that training specificity is a reflection of the interplay between peripheral and central adaptations. More specifically, Lieber et al stated that support for the concept of training specificity seems to occur when training elicits muscular peripheral adaptations without accompanying central (CVS) adaptations. This situation arises when a relatively small muscle mass is trained; and when the total metabolic demand during training is insufficient to cause significant CVS adaptation.

This viewpoint is supported by the research of Magel et al (1978) that has been previously discussed in this review. These researchers agree that when the effective muscle mass trained is limited, as in arm work, the improvement in aerobic capacity is largely the result of peripheral adaptations since the total metabolic demand/stress during arm work may be insufficient to cause central circulatory adaptations.

Therefore, it may be suggested that the arm ergometry (AR) training in the Magel et al (1978) study, at 85% of AR maximal heart rate (which is equivalent to 50% of running $\dot{V}O_2$ max.), was insufficient to elicit a significant central adaptation. This suggestion is supported by the observation that 88% of the enhanced arm ergometer $\dot{V}O_2$ max. shown in the study, was due to increased arterio-venous oxygen content difference- (an indication of peripheral adaptations).

This integrated view of the interplay between peripheral and central adaptations to specific training, is also supported by the research of Ekblom et al (1968b) and Saltin et al (1976). Clausen et al (1973) added to this viewpoint by suggesting that central and peripheral adaptations may counteract each other; and that this antagonism may explain some of the conflicting research in the field of circulatory effects of training.

The "Lieber et al" viewpoint may be applied to the research of Davies et al (1975). These researchers investigated the effect of one-leg training on a bicycle ergometer, over a period of 6 weeks. The following improvements in a cycling $\dot{V}O_2$ max. test

were found: right leg alone:	16%
left leg alone :	12%
both legs together:	4%

This research thus supported the concept of training specificity. In applying the Lieber et al viewpoint, one may explain the results reported by Davies et al (1975) in the following way: Since the quantity of exercising muscle mass was small, the CVS adaptations that resulted from one- leg training may have not been sufficient enough to cause the CVS adaptations necessary to produce similar $\dot{V}O_2$ max. improvements for two- leg exercise.

The study of Rathnow and Magnum (1990) was similar to that of Lieber et al (1989), since both studies accurately controlled the training intensity and volume of the different training groups in their studies. The findings of Rathnow et al though, support the concept of training specificity. The effect of a multi-modal endurance training program as opposed to a single mode training program on aerobic power, was investigated.

Twenty, sedentary subjects were randomly assigned to either a ten week multi-modal (walk/jog; cycle; arm crank) training program or to a ten week single mode (walk/jog) training program.

Training workloads were set (and validated by indirect calorimetry) for all three modes of exercise, such that energy expenditures for the single mode and multi mode groups were equivalent. Furthermore, all subjects trained at 50-60% of their peak $\dot{V}O_2$ for each exercise mode.

After the training period, the single mode training group showed a greater treadmill $\dot{V}O_2$ peak than that of the multi-mode training group. However, the single mode group showed no changes in their peak $\dot{V}O_2$ for cycle ergometry and arm ergometry. There were no changes in peak $\dot{V}O_2$ for all three exercise modes, in the multi-modal training group.

Rathnow et al (1990) explained these findings on the basis that central responses to exercise are highly dependent upon peripheral vascular modifications, and not only on cardiac adaptations. Therefore, although total duration and intensity of the workouts in their research were theoretically sufficient to change peak $\dot{V}O_2$, no limbs received stimuli sufficient to induce peripheral vascular adaptations. Thus, no actual changes in peak $\dot{V}O_2$ occurred.

The contradictions in the findings of the Lieber et al (1989) and Rathnow et al (1990) studies, may be due to:

a) The different training intensities of the two studies. Subjects trained at a higher intensity in the Lieber et al study.

b) The one study compared a swim training program to a running training program, while the other study compared a walk/jog; cycle; arm ergometry program to a walk/jog training program. In this context, one might consider that arm-ergometry training involves different mechanics and muscle groups to those involved in free swim training.

The research of Roberts and Alspaugh (1972) and Pechar et al (1974) support the findings of Lieber et al (1989). These studies demonstrated similar improvements in peak $\dot{V}O_2$ with treadmill and cycle testing after a period of treadmill running training.

Rathnow et al (1990), highlight another factor present in the above two studies, that may contribute to explaining the variable results of cross-training studies - i.e. as opposed to other studies, high-speed, grade running was utilised in the training regimes of Roberts et al (1972) and Pechar et al (1974). This difference could produce variable results, because of variation in muscle groups utilized or motor unit recruitment. For example, uphill high speed running approximates cycling muscle action more than does low speed, flat grade running.

A cross-training effect is also evident in the research of Eyestone et al (1993), who found that recreational runners can maintain their running VO_2 max. and 2-mile run time by water running or water cycling. The effect of the water running or water cycling training was similar to that of regular running training, and maintenance of VO_2 max. and run-time occurred regardless of fitness level. These researchers emphasized that maintenance effects can only be achieved if the water cycling or running are performed at an intensity, duration and frequency equivalent to that of running training.

Hickson et al (1985) also supported the notion that the intensity of alternative training needs to be similar to actual running training intensity in order to maintain running VO_2 max. and performance levels.

1.7) CONCLUSION

Research in the field of cross-training (especially pertaining to short-distance type training), seems equivocal.

Comparing different research data and their conclusions becomes difficult, since studies have used:

i) subject groups of different fitness levels; ii) different $\dot{V}O_2$ max. testing protocols; iii) different absolute and relative training intensities; iv) different exercise modes; and v) different amounts of muscle mass exercised in the various training modes.

1.8) FUTURE RESEARCH RECOMMENDATIONS

The following areas need further investigation in the context of cross-training studies:

i) The effect of training regimens on performance specific tests, as opposed to the effect on $\dot{V}O_2$ max. tests.

ii) The effect of short-distance (interval) training programs in one mode of activity on another mode of activity.

iii) More studies are needed where training intensity, volume, and energy expenditure are accurately controlled and measured within and among different training groups of the study.

iv) Running in water elicits different physiological responses to swimming in water (Bishop et al, 1989; Svedenhag et al, 1992). The cross-training effects between running in water and running on land need to be investigated.

v) Many investigators suggest that the type of muscle fiber composition of athletes is explained by genetic factors and natural selection of athletes, rather than by training program factors (Shenkman et al, 1989).

However, it would be interesting to examine the influence of different types of muscle fiber compositions on the ability of an athlete to exhibit a crosstraining effect.

CHAPTER 2

INTRODUCTION

Cross-training has been defined as deriving benefits in the performance of one mode of activity, through training done in another mode of activity (Claussen et al, 1973). One has to expand this definition when considering the newer disciplines of duathlons, biathlons and triathlons. Cross-training in the context of these activities, becomes a question of establishing the ideal amounts of training in each of the two or three sport modes for optimising performance and minimising the occurrence of overuse injuries (O'Toole et al, 1989).

Most of the studies in the field of cross-training have investigated long-distance duathlons and triathlons, or the effects of long-distance type training in one mode of activity on the performance of another mode of activity. The effects of middle distance type training in one sport mode on the performance of another sport mode however, have been less extensively researched.

Furthermore, the evidence of many studies strongly support the principle of training specificity which suggests that training adaptations are specific to the mode of training (McArdle et al, 1971, 1978; Roberts & Morgan, 1971; Clausen et al, 1973; Davies & Sargeant, 1975; Magel et al, 1975, 1978; Rasmussen et al, 1975; Stromme et al, 1977; Wilmore et al, 1980; Gergley et al, 1984; Gwinup, 1985; Kohrt et al, 1987a, 1989).

Some studies however, have shown a cross-training effect between two exercise modes (Roberts & Alspaugh, 1972; Pechar et al, 1974; Pollock et al, 1975; Kohrt et al, 1987b; Lieber et al, 1989; Eyestone et al, 1993).

One should consider though, that most studies have used changes in maximal oxygen consumption ($\dot{V}O_2$ max.) as the major measure of response. It may be the case that performance in one activity may improve through training in another activity, without a concurrent increase in $\dot{V}O_2$ max. (Kohrt et al, 1989; O'Toole et al, 1989; Costill et al, 1991).

This may be particularly applicable to short-distance type activities that utilise large portions of anaerobic energy.

This study will aim to assess the cross-training effects between short-distance running and swimming, by investigating the influence of interval swim training on middle-distance type running events and on treadmill $\dot{V}O_2$ max.

The reasons for investigating the topic of cross-training, include:

- i) The efficacy of training in a multi-disciplinary sport, such as the biathlon, where individuals compete over short distances in swimming and running, at different times.
- ii) The use of low impact, multi-sport training as a means of distributing strain over different body parts and reducing overuse injuries.
- iii) The use of appropriate activity during the active rest macrocycle of a periodized training programme.
- iv) The use of appropriate activity during the recovery of an injury related to running activities, i.e. the use of a low impact activity, like swimming, to prevent total detraining during the rehabilitation of an injury.

CHAPTER 3

METHODS

3.1 Subjects

Fourteen, sedentary subjects aged between 21 and 30 years , initially volunteered to participate in the study. Complete data however, were obtained from only eight subjects (4 males; 4 females). The physical profile of these subjects is depicted in Table 1. Six subjects could not adhere completely to the training program and testing due to illness and work commitments.

All subjects were in an untrained state at the beginning of the study. Subjects had not exercised for a minimum period of twelve months, with the exception of one subject (three months). Furthermore, the subjects had minimal prior experience in a structured running or swimming training programme.

Each subject signed a statement of informed consent, and ethical clearance for the study was obtained from the Committee for Research on Human Subjects, University of the Witwatersrand.

Table 1: Physical profile of subjects (n=8)

	MEAN	± SD
AGE (years)	24.63	2.77
HEIGHT (cm)	167.34	7.22
WEIGHT (kg)	62.60	13.87
VO ₂ Max. (ml/kg.min)	42.06	5.10

3.2 Procedures

3.2.1 Testing

The following responses were measured before and after a 12 week swimming training program, within a 14 day period:

3.2.1.1 Running economy. After a 10 minute warm-up period, each subject ran on a motorised treadmill (Powerjog E10 UK) at a measured submaximal load (12 kph, 0% elevation) for 5 minutes, while steady state oxygen consumption (VO₂) was measured. Oxygen consumption was measured by an on-line system (Oxycon 4 Mijnhardt, Netherlands), every 30 seconds.

Running economy (RE) was calculated from:

$$RE = VO_2 \text{ (ml/min.kg)} / \text{Velocity (km/min)}$$

3.2.1.2 VO₂ max. An intermittent incremental treadmill protocol was used to measure VO₂ max.

The speed of the treadmill was kept constant at 13.0 kph and the elevation changed by 1% increments. $\dot{V}O_2$ max was attained when the steady state $\dot{V}O_2$ changed by less than 1.5 ml/min.kg with a 1% increment in elevation. Running $\dot{V}O_2$ max was measured because this study wished to examine the influence of swim training on running physiology and performance.

3.2.1.3 Wingate anaerobic power. A Cateye Cyclosimulator (model CS 1000, Japan) cycle ergometer was used to assess anaerobic capacity. After a 5 minute warm-up, an appropriate load and a gear ratio was selected which yielded a predetermined optimal power output (Bar-Or, 1987). After a 5 minute rest the subject pedalled as hard and as fast as possible for 30 seconds. Power output was recorded every 5 seconds.

3.2.1.4 Dynamometry. Muscle function was assessed using an Akron Isokinetic Dynamometer (3000 C; United Kingdom). Torque during knee extension/ flexion and shoulder extension/ flexion was measured for both the right and left lower and upper limbs respectively. Three measurements were performed on each limb: a) 15 seconds at 60 °/sec.; b) 25 seconds at 160 °/sec. for the legs and at 195 °/sec for the shoulders; and c) 35 seconds at 245 °/sec. The latter testing velocity was used as a measure of muscle endurance.

A warm-up period of sub-maximal load repetitions was used to warm-up the appropriate muscle groups before the start of each strength test.

3.2.1.5 Swimming and running performance responses. A 100m and a 200m swim time trial were performed four times on four different days. Similarly, a 400m and a 800m time trial were run four times on four different days. Running and swimming time trials never took place on the same day.

The order of the testing for the runs and the swims was randomised (refer Table 2), but the order in the post-training phase of testing was kept the same as that which occurred in the pre-training testing phase.

All four time trials for each distance were averaged, and a coefficient of variation was calculated. The coefficient of variation did not exceed 10% for any of the time trials, before as well as after training. During the pre- and post-training testing period, every third day was a rest day in order to avoid fatigue.

Table 2: Testing order of swim and run time-trials

Testing session		1	2	3	4
Test mode		Run Swim (metres)	Run Swim (metres)	Run Swim (metres)	Run Swim (metres)
Subjects	1	800 100 400 200	400 200 800 100	800 100 400 200	400 200 800 100
	2	400 100 800 200	800 200 400 100	800 200 400 100	400 100 800 200
	3	800 200 400 100	400 100 800 200	800 100 400 200	400 200 800 100
	4	400 200 800 100	800 100 400 200	800 200 400 100	400 100 800 200
	5	400 200 800 100	800 100 400 200	400 200 800 100	800 100 400 200
	6	400 200 800 100	800 200 400 100	800 100 400 200	400 100 800 200
	7	800 200 400 100	400 100 800 200	800 200 400 100	400 100 800 200
	8	800 200 400 100	800 100 400 200	400 200 800 100	400 100 800 200

* The first distance run or swum appears on the top line
Only one sport mode was tested per testing session

3.2.2 The training programme

The 12 week training period was based on a periodized programme. The first four weeks consisted of aerobic based training, followed by eight weeks of interval training, of progressively increasing intensity.

The first four weeks were implemented as a general conditioning phase and allowed subjects to get familiarized with swimming training. Thus, the intensity of training during this phase was kept low to moderate- (50 - 75% of maximum effort). The following eight weeks involved more intense, short-distance, interval type training- (80 - 100% of maximum effort).

Training intensity was established by applying the concept of percentage effort. At the start of the training programme and thereafter at four weekly intervals, each subject swam at maximal pace over 100m and over 200m. The times recorded were indicative of 100 percent effort.

Percentages of maximum effort were then expressed as training times via use of the following formula:

$A = B (200 - E) / 100$; where A = training time (secs); B = time-trial (secs); and E = % effort.

An attempt was made to equate training intensity for 100m and 200m swimming, to that of training for 400m or 800m running.

Subjects were timed during their training sessions in order to ensure that each subject adhered to the designated training effort. In this way training intensity was kept equivalent for all subjects, thus maintaining the training principle of individuality.

The training principle of overload and progression were applied on a weekly basis, when training volume and/or training intensity were increased. Every fourth week however was a regeneration week, when training intensity was kept constant and training volume was reduced. During the regeneration week, time trials were performed so that training progression could be adjusted for increases in fitness levels.

Table 3 describes the swimming training programme that was used in this study. As can be seen from the last two columns of Table 3, short training intervals were used to primarily activate short-term energy pathways via phosphagen stores and glycogen. Thus, the energy pathways activated during the swim training were equivalent to those activated during 400m and 800m running.

Subjects were also asked to record their morning, resting heart rate daily, during the 12 week training period. Morning heart rates above 80 bt/min. had to be reported. This type of feedback was used to prevent training during illness.

Table 3: Description of the 12 week swimming training programme

WEEK	FREQUENCY - times/week	VOLUME - total distance (m) per session	INTENSITY - % of peak pace	Shortest interval (m) per session	Longest interval (m) per session
1	3 - 4	1150	50 - 70	100	150
2	3 - 4	1400	65 - 75	100	150
3	3 - 4	1750	80	175	200
4	2 times	500	Time-trials	100	200
5	3 - 4	1500	80 - 85	75	150
6	3 - 4	2000	85 - max	25	125
7	3 - 4	2550	80 - 85	50	250
8	2 times	550	Time-trials	100	200
9	3 - 4	2300	85	50	150
10	3 - 4	2700	90 - max	25	150
11	3 - 4	2950	90 - 95	100	175
12	2 times	2200 - 1500	90	50	175

3.3 STATISTICAL ANALYSIS

All pre- and post-training values were compared using the t-test for dependent data. In addition, all run and swim performance results were tested for significance by repeated-measures analysis of variance. The null hypothesis was rejected at the 5% level.

CHAPTER 4

RESULTS

4.1 Swimming

4.1.1 Physiological changes (shoulder dynamometry)

Table 4 and 5 depict pre- and post-training mean values for peak torque; power and work measures during shoulder flexion and extension isokinetic tests. Measures of power and work at 195 °/sec and at 245 °/sec showed significant improvements after swim training.

Table 4: Mean ($\pm$ SD) values for shoulder flexion isokinetic tests

PEAK TORQUE (Nm/kg)						
Speed (deg/sec)	60		195		245	
Pre-training	1.01	(± 0.18)	1.02	(± 0.24)	1.02	(± 0.27)
Post-training	1.07	(± 0.14)	1.05	(± 0.17)	1.03	(± 0.20)
POWER (Watts)						
Speed (deg/sec)	60		195		245	
Pre-training	48.35	(± 22.73)	95.70	(± 49.63)	93.50	(± 49.31)
Post-training	50.07	(± 21.06)	106.86	(± 51.89)**	99.68	(± 50.77)*
WORK (Joules)						
Speed (deg/sec)	60		195		245	
Pre-training	359.45	(± 173.25)	1 152.59	(± 613.87)	1 559.78	(± 817.17)
Post-training	367.54	(± 148.41)	1 282.93	(± 618.39)**	1 736.79	(± 809.59)*

* Significant differences between pre- and post-training values ($p < 0.05$)

** Significant differences between pre- and post-training values ($p < 0.001$)

Table 5: Mean ($\pm$ SD) values for shoulder extension isokinetic tests

PEAK TORQUE (Nm/kg)				
Speed (deg/sec)	60		195	
Pre-training	0.98	($\pm$ 0.24)	0.91	($\pm$ 0.19)
Post-training	0.96	($\pm$ 0.17)	0.91	($\pm$ 0.14)
POWER (Watts)				
Speed (deg/sec)	60		195	
Pre-training	42.19	($\pm$ 21.50)	76.14	($\pm$ 45.18)
Post-training	43.06	($\pm$ 20.31)	87.74	($\pm$ 47.56)**
WORK (Joules)				
Speed (deg/sec)	60		195	
Pre-training	311.37	($\pm$ 157.42)	912.74	($\pm$ 526.91)
Post-training	322.66	($\pm$ 159.58)	1 055.09	($\pm$ 569.89)**

* Significant differences between pre- and post-training values ($p < 0.05$)

** Significant differences between pre- and post-training values ($p < 0.005$)

4.1.2 Performance changes (Swim time trials)

The 100m swim times improved by 20% after swim training. This change was found to be significant ($p < 0.05$). Similarly, the 200m swim times improved by 22% ($p < 0.05$) (Figures 1 and 2).

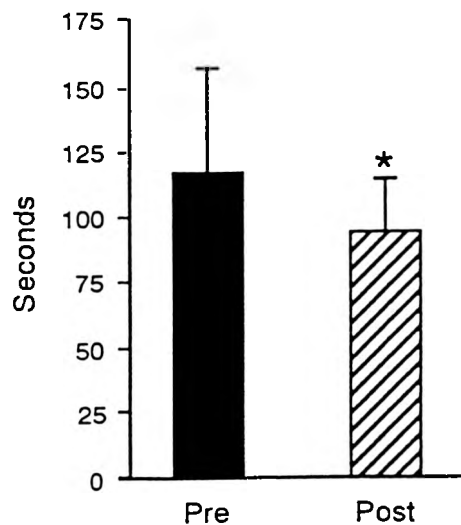


Fig.1 : Pre- and post-training 100m free-style swim times (sec)

(* Significant differences between pre- and post-training values - $p < 0.05$)

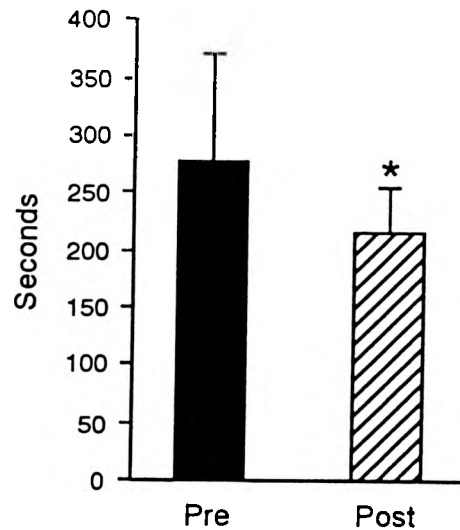


Fig.2 : Pre- and post-training 200m free-style swim times (sec)
 (* Significant differences between pre- and post-training values - $p < 0.05$)

4.2 Running

4.2.1 Physiological changes

4.2.1.1 $\dot{V}O_2$ max and Running economy

Pre- and post-training values for weight, $\dot{V}O_2$ max and running economy are shown in Table 6.

Significant differences between pre- and post-training values were evident only for $\dot{V}O_2$ max ($p < 0.005$).

4.2.1.2 Knee Dynamometry

Results for power and work at 60 °/sec changed significantly during knee flexion tests after swim training (Table 7). Significant changes were also found for power and work measures during knee extension at 245 °/sec (Table 8).

Table 6: Mean (SD±) values for weight, VO₂ Max. and running economy before and after swim training

VARIABLE	PRE-TRAINING	POST-TRAINING
Weight (kg)	62.60 (± 13.87)	63.40 (± 13.45)
VO ₂ Max. (l/min)	2.68 (± 0.88)	2.87 (± 0.89)*
VO ₂ Max. (ml/kg.min)	42.06 (± 5.10)	45.39 (± 5.05)*
Running economy (ml/kg.km)	173.98 (± 9.05)	182.11 (± 18.51)

* Significant differences between pre- and post-training values (p< 0.005)

Table 7: Mean (± SD) values for knee flexion isokinetic tests

PEAK TORQUE (Nm/kg)						
Speed (deg/sec)	60		160		245	
Pre-training	1.73	(± 0.16)	1.72	(± 0.17)	1.55	(± 0.21)
Post-training	1.83	(± 0.25)	1.80	(± 0.28)	1.54	(± 0.22)
POWER (Watts)						
Speed (deg/sec)	60		160		245	
Pre-training	75.58	(± 25.36)	135.16	(± 47.55)	135.42	(± 48.00)
Post-training	82.54	(± 24.61)*	149.05	(± 45.17)	142.26	(± 45.70)
WORK (Joules)						
Speed (deg/sec)	60		160		245	
Pre-training	538.30	(± 166.47)	1 606.93	(± 557.26)	2 213.21	(± 771.93)
Post-training	587.35	(± 184.03)*	1 785.34	(± 556.01)	2 305.72	(± 725.87)

* Significant differences between pre- and post-training values (p<0.05)

Table 8: Mean ($\pm$ SD) values for knee extension isokinetic tests

PEAK TORQUE (Nm/kg)					
Speed (deg/sec)	60		160		245
Pre-training	2.57	(± 0.37)	1.93	(± 0.28)	1.59 (± 0.34)
Post-training	2.37	(± 0.48)	2.02	(± 0.35)	1.75 (± 0.33)
POWER (Watts)					
Speed (deg/sec)	60		160		245
Pre-training	91.39	(± 29.11)	150.49	(± 53.63)	121.88 (± 44.92)
Post-training	89.46	(± 34.03)	161.87	(± 71.18)	138.22 (± 58.41)*
WORK (Joules)					
Speed (deg/sec)	60		160		245
Pre-training	675.49	(± 230.72)	1 778.95	(± 649.56)	2 005.13 (± 744.97)
Post-training	670.44	(± 247.16)	1 903.53	(± 822.24)	2 263.31 (± 947.25)*

* Significant differences between pre- and post-training values ($p < 0.05$)

4.2.1.3 The Wingate Test

No significant changes were found with the Wingate Anaerobic Power Test after compared to before swim training (Table 9).

Table 9: Summary of Wingate Test results before and after swim training

TEST MEASURE	PRE-TRAINING		POST-TRAINING	
Peak Power (W)	670.63	($\pm$ 222.71)	722.88	($\pm$ 236.93)
Peak Power (W/kg)	10.48	($\pm$ 1.71)	11.34	($\pm$ 2.38)
Mean Power (W)	530.09	($\pm$ 182.37)	555.80	($\pm$ 169.99)
Mean Power (W/kg)	8.26	($\pm$ 1.43)	8.71	($\pm$ 1.33)
Power loss (%)	29.34	($\pm$ 10.48)	31.04	($\pm$ 11.41)

4.2.2 Performance changes

4.2.2.1 Run time trials

The 400m run times showed a 6% improvement after swim training. This change was found to be statistically significant ($p < 0.05$) (Figure 3).

Similarly, the 11% improvement in the 800m run times was found to be significant ($p < 0.005$) (Figure 4).

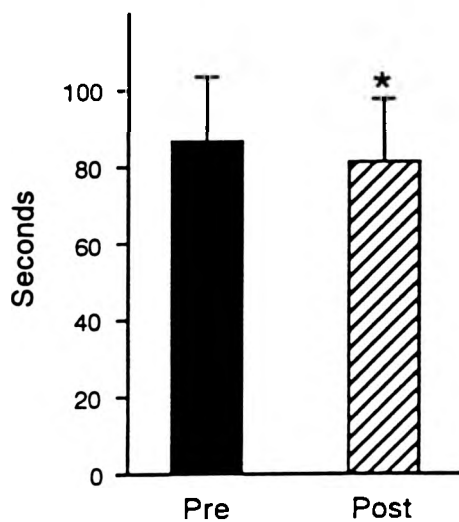


Fig.3 : Pre- and post-training 400m run times (sec)

(* Significant differences between pre- and post-training values - $p < 0.05$)

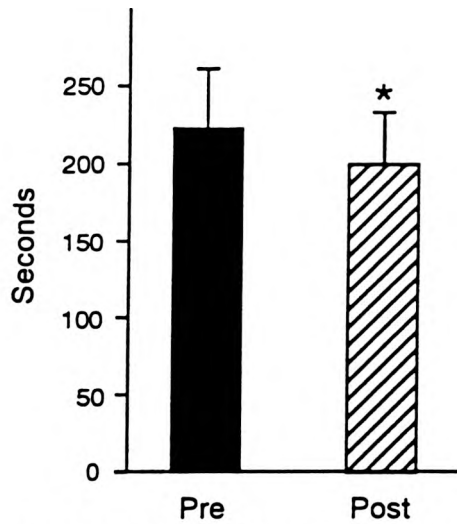


Fig.4 : Pre- and post-training 800m run times (sec)

(* Significant differences between pre- and post-training values - $p < 0.005$)

In addition, repeated- measures analysis of variance was applied to all the run and swim performance responses (Table 10). The analysis confirmed that the differences between all pre- and post- training repeats for all run and swim time trials were significant ($p < 0.0001$).

Table 10: Summary of repeated-measures analysis of variance on run and swim performance measures using a general linear models procedure

PERFORMANCE MEASURE	100 m swim times	200 m swim times	400 m run times	800 m run times
F-RATIO	14.75	73.17	60.71	40.33
R-SQUARED	0.82	0.96	0.95	0.93
P-VALUE	0.0001	0.0001	0.0001	0.0001

CHAPTER 5

DISCUSSION

5.1 Swimming

The shoulder dynamometry results indicate that the 12 week swimming program elicited an upper limb training response. Significant changes were found in power and work at higher testing speeds (195 °/sec and 245 °/sec), during shoulder flexion and extension (Table 8 and 9). Thus, shoulder flexor and extensor muscles showed improvement in power output and muscle endurance following swim training.

The swim training also resulted in a significant improvement of the 100m and 200m swim times (Figures 1 and 2). This confirms that the swim program elicited a significant training response.

5.2 Running

Interval swim training elicited changes in running based physiological measures. Treadmill $\dot{V}O_{2\max}$ improved after 12 weeks of swim training (Table 3). The improvement indicated a change in oxygen-dependent energy producing pathways.

This result is in agreement with the research of Holmer et al (1974b) and Lieber et al (1989). Contrary to the results of this study though, Magel et al (1975) found no significant improvement in treadmill $\dot{V}O_2$ max. among recreational swimmers, after ten weeks of interval swim training. The research of Gergley et al (1984) and Clausen et al (1973) provide additional evidence to support the findings of Magel et al (1975) and the principle of training specificity.

Reasons for contradictory research with regard to the specific response of $\dot{V}O_2$ max. to training mode may include:

i) The dissimilar $\dot{V}O_2$ max. testing protocols utilised by the different research laboratories.

ii) Subject level of ability and trained state.

This factor has been shown to influence research results (Reilly, 1990). Clarys (1985) showed that trained elite swimmers utilise a greater muscle mass than less trained, recreational swimmers during swimming. This may influence oxygen consumption and training energy expenditure values, which in turn makes it difficult to compare studies involving swimmers of dissimilar fitness and ability levels.

The present study only investigated untrained, non-elite swimmers. Thus, the results may apply only to individuals of a low fitness level.

iii) The training program utilised

The different training program intensities, volumes and durations applied by the various researchers may also explain some of the disparity among research evidence.

In addition, subject groups within a cross-training study may be training at dissimilar intensities. This possibility was pointed out by Pechar et al (1974) who stated that an intensity of 85% of maximal heart rate (MHR) during cycling training may not be the same as that of 85% MHR during treadmill training, since the general cardiorespiratory response is less during cycling than during treadmill training.

The study of Lieber et al (1989) though, ensured that absolute training volume and relative training intensity of their swim- and run- training groups were similar. More specifically, these researchers examined the effect of 11 weeks of endurance training in running and swimming, on treadmill VO_2 max. The increase in treadmill VO_2 max. of the run- trained group was found to be no different to the increase achieved by the swim-trained group.

Lieber et al concluded that when training intensities and volumes are kept similar between training groups of different exercise modes, a cross-training effect can occur.

The improvement of treadmill $\dot{V}O_2$ max. after swimming training, found in the present study, also indicates an improvement in swimming $\dot{V}O_2$ max. This statement is based on the research of Montpetit et al (1981) and Bishop et al (1989) who found a linear relationship between swimming $\dot{V}O_2$ peak and treadmill $\dot{V}O_2$ peak for recreational swimmers.

The fact that running economy did not show any changes after swim training was expected, since swim training has been shown to not influence running efficiency.

Swim training also influenced the Knee flexion and extension isokinetic dynamometry (Table 6 and 7). Knee flexion tests showed significant changes in measures of power and work at 60 °/sec. In contrast, knee extension tests showed significant improvements in levels of power and work at higher speeds (245 °/sec). Thus an increase in muscle power output and the ability to perform a greater amount of work was evident in the knee extensors and flexors after swimming training.

Muscle strength around the knee joint, as measured by peak torque values at 60 °/sec though, did not change with swimming training.

The findings of the dynamometry tests of this study indicate that power output of the knee and shoulder, flexor and extensor muscle groups can be improved through interval swim training. Swimming training was also shown to improve muscular endurance of the knee extensors and of the shoulder flexors and extensors. These increases may have contributed to the improvements in swimming and running performances (Figures 1 - 4).

The Wingate test did not show any differences between pre- and post -training values. Considering that run and swim performance responses improved, the Wingate test may not have been specific enough to depict changes in oxygen-independent energy pathways after swim training.

A training program may cause changes in performance without a concurrent increase in $\dot{V}O_{2\max}$ values (Kohrt et al, 1989; O'Toole et al, 1989; Costill et al, 1991). This is applicable to short distance training that primarily utilizes oxygen-independent energy pathways.

This study thus also measured run performance times after a period of short distance swim training. A cross-training effect of swim training on running performance was clearly demonstrated by the 400m and 800m run performances.

Run times improved significantly after swimming training (Figure 3 and 4; Table 4).

In support of this finding, Kohrt et al (1987b) also found evidence of cross-training in their research. These researchers reduced cycling and swim training among triathletes by 60% and 72% respectively. At the end of a three month period, running and cycling VO_2 max had decreased, yet swimming VO_2 max had been maintained. Kohrt et al cited cross-training as one possible explanation for their results, i.e. swimming capacity could be maintained by non-specific training (running).

A cross-training effect was also demonstrated in the research findings of Roberts et al (1972) and Pechar et al (1974). Similar improvements in peak VO_2 with treadmill and cycle testing were demonstrated in these studies after a period of running training. Furthermore, Eyestone et al (1993) found that recreational runners can maintain their running VO_2 max and two-mile run time by water running or water cycling that is of an intensity, duration, and frequency equivalent to that of land running training.

Magel et al (1975) however, found no change in treadmill VO_2 max in recreational swimmers after ten weeks of interval swim training. Maximum treadmill run time though, increased. Thus, in support of the present study, run performance responses improved after swim training.

A viewpoint proposed by Lieber et al (1989) and supported by Ekblom et al (1968); and Magel et al (1978) will be used to offer a possible explanation for the results of this study. This viewpoint suggests that training specificity is a reflection of the interplay between peripheral and central adaptations- i.e. training specificity seems to occur when training elicits muscular peripheral adaptations without accompanying central cardiovascular adaptations. This situation arises when a relatively small muscle mass is trained; and when total metabolic demand / load during training is insufficient to cause significant central adaptations.

In applying this viewpoint, the swimming training program used in the present study may have recruited a large enough muscle mass and may have demanded a sufficiently high level of metabolic activity to cause significant central adaptations. In this way, the swim training intensity (load) and volume that was applied elicited muscular peripheral adaptations with accompanying central adaptations. Thus a cross-training effect was exhibited.

However, one must consider that this explanation was used to explain cross-training in studies that investigated endurance type training programs. Thus, it may not be applicable to this study which utilised an interval training program.

The improvements in the 400m and 800m run times may also be attributed to the energy systems stimulated during swimming training. The short training distances and moderate to high training intensities used in this study, were specifically chosen to primarily stimulate oxygen-independent metabolism via phosphagen stores and glycolysis. In this way, the same primary energy system that is used during the 400m and 800m run was "trained" in the water.

It follows, that if similar energy systems involved in one mode of activity are stimulated during training in another mode of activity and if sufficient overlap between functional muscle fibres exists between swimming and running, a cross-training effect may be elicited.

Thus, the training intensity; frequency; and duration used in this study's swim program may have been equivalent enough to those of running training for 400m and 800m events. Consequently, a cross-training effect between swimming and running was attained.

The present study supports the conclusion of Lieber et al (1989) that training specificity may not only be influenced by training in different modes of activity; but also by training intensity, training volume, and fitness level.

CHAPTER 6

CONCLUSION

Cross- training may help prevent overuse injuries and overtraining. Cross- training may also be effectively utilised in the rehabilitation of an injury. Research in the field of cross- training however, seems equivocal due to the following methodological issues:

a) Subject fitness level; b) VO_2 max. testing protocols; c) Volume, intensity and duration of training programs; d) Energy expenditure during training sessions; and e) the size of the muscle mass exercised.

This study found a cross- training effect between swimming and running with untrained, non-competitive swimmers.

While mode of activity was non-specific in this study, a training response was attained by keeping the training intensity and volume of the swim training specific to middle-distance run training.

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