Metabolic responses to supramaximal exercise and training

A GENDER COMPARISON

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DECLARATION

This work has not previously been submitted for a degree or diploma in any university. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due references is made in the thesis itself.

.............................
Clare L. Weber
“It is considered that a woman is only about 50 per cent. as efficient athletically as a man, and there are plenty of avenues for her energy without invading the spheres which men have developed. I would seriously recommend those [women] who will take part in sports to practice regularly a set of scientifically designed exercises everyday to build up any weak sections.”

PROFESSOR CLARENCE A. WEBER
VICTORIAN HEALTH & STRENGTH COLLEGE
Many experts in the field argued that the early 1900’s was the most significant era for women in sports. At that time, there was not only an increase in participation, but women’s involvement in sports increased at the Olympic level. Indeed, since 1930, female athletes have narrowed the gender gap in athletic performance. However, my interest in the area of gender differences in metabolism arose from observations of the remaining ~10% margin that exists between male and female performance in sprint-type events.

Sydney, Australia, 2000; Marion Jones had barely finished her victory lap when Maurice Greene joined her as an Olympic 100-m champion. I was curious as to why the fastest female sprinter over 100 m was taller than the fastest male sprinter, yet weighed 10 kg lighter. Could the 0.88 s margin in their medal winning performances be solely accounted for by a difference in lean body mass? Of even greater interest to me was the wider margin evident between men and women in the middle-distance events; events that virtually exhaust the capacity of the anaerobic energy systems while demanding a maximal rate of oxygen uptake.

Intuitively, it seems reasonable to suggest that investigations into gender differences in metabolism are important. In reality, evidence is required to support the suggestion that differences in both anaerobic and aerobic metabolism exist between men and women during exercise. Metabolic disparity between men and women may contribute to the varying success of exercise training programs and to athletic performance. Consequently, there is a need for additional studies that examine the effects of gender on the metabolic response to exercise and training. As researchers have previously asked whether what is true of men is also true of women, the answer has been virtually the same in every case - not precisely.

When I began this work, the purpose was to compare the maximal capacity of the anaerobic energy systems between men and women. After examining the data collected before and after training, it was apparent that aside from the anaerobic energy systems, aerobic metabolism made an important contribution to successful performance during sprint-type activity. At that point, I considered the rate response of pulmonary oxygen uptake in an effort to gain a greater understanding of aerobic
metabolism at the onset of exhaustive, short-duration exercise. Thus, the focus of this work is across two principal areas of measurement: anaerobic capacity and oxygen uptake kinetics. Furthermore, the two key themes that are consistent throughout this thesis are gender and supramaximal exercise. These four expressions are described below.

**Anaerobic capacity** is the maximum amount of adenosine triphosphate that can be regenerated anaerobically during a single bout of exercise. Here, anaerobic capacity is determined by measuring the maximal accumulated oxygen deficit during exhaustive, short-duration exercise. **Oxygen uptake kinetics** reflect the readjustment of oxidative phosphorylation to meet the new ATP demand after a step increase in work rate. In the present thesis, pulmonary oxygen uptake is described using mathematical modeling. **Gender** is used in preference to 'sex' throughout this thesis. There has been some discussion as to the terminology of 'sex' versus 'gender'. However, I am not aware of the technically correct expression. **Supramaximal exercise**: to the well-established cardiorespiratory physiologist, heavy or severe exercise may be characterized by exercise performed at any intensity that is above the work rate achieved at the ventilatory threshold. Thus, I have chosen to use the term 'supramaximal' specifically to describe exercise that is performed at an intensity greater than that which corresponds to the maximal rate of oxygen uptake.

This thesis is written in six parts: Chapter 1 provides an overview to anaerobic and aerobic metabolism. The maximal accumulated oxygen deficit and the oxygen uptake response to supramaximal exercise are explored as indirect measures of anaerobic and aerobic ATP production, respectively. Gender-specific differences in the mechanisms that drive anaerobic and aerobic metabolism is the primary focus and the research aims are presented in the final section of Chapter 1. Chapter 2, 3 and 4 represent three research experiments that systematically address the research aims. These chapters include independent introduction, method, result and discussion sections. Chapter 2 is a comprehensive evaluation of the reliability of the maximal accumulated oxygen deficit measured at two exercise intensities in both men and women. Chapter 3 examines the changes in the maximal accumulated
oxygen deficit and compares anaerobic and aerobic metabolism before and after short-duration, high-intensity interval training in both men and women. Chapter 4 focuses on the oxygen uptake response in men and women at the onset of moderate-intensity and supramaximal exercise before and after 8 wk of high-intensity interval training. Chapter 5 presents a statement of conclusions that summarize the findings of all the experiments. Chapter 6 provides information to assist the reader in setting up a laboratory, in testing a subject, and making the necessary calculations. This will help to enhance the readers understanding of the technical aspects of the measurements and calculations used in this thesis. In addition, the reader will find justification for the methods used throughout this thesis and a description of any limitations or assumptions accepted in this thesis.

In summary, when the current exercise physiology curriculum is reconsidered, it should not simply add paragraphs to every section of the textbook describing women’s unique response to exercise, nor should it simply offer a single lesson on the female athlete presented in a chapter entitled ‘special population groups’. Rather, it should challenge and revise existing views on the response to exercise and training for each gender, having demonstrated that it will truly make a difference to current practice. However, if we are going to move ahead, it is essential to respond to the most important question asked by the skeptic: “Where is the evidence?”

Clare L. Weber
ACKNOWLEDGEMENTS

I am delighted to acknowledge my colleagues, friends and family for the support and inspiration I have received over the period of my doctoral candidature. To my chief supervisor, Dr Donald Schneider, thank you for this productive partnership. Your perseverance for good research is exceptional and your ability to absorb my frustrations is remarkable. To Professor Gregory Gass, thank-you for creating this wonderful environment that facilitates inquiry and discovery. I truly enjoyed our conversations on the topics of altitude training and national politics. The commitment that you offer your students is outstanding.

I would like to thank Professor Lewis Adams for making positive criticisms and offering valuable encouragement during the critical stages of this work. To the School of Physiotherapy and Exercise Science administration staff, thank you for always finding time for me. In addition, I will be forever grateful to the participants
involved in each of these experiments for their dedication, exertion and genuine interest.

To my colleagues Justin Keogh, Dale Lovell, and Surendran Sabapathy, I will always cherish the time we spent in deep discussion, drowned in laughter or simply sharing the harmony of our office. To my precious friends overseas and interstate, your detailed descriptions of the African Horizon, Greek Island Sunsets, and the mystery of the Egyptian Pyramids at times had me restless for adventure. Thank-you for believing in me and offering continual encouragement and support that helped me to remain focused.

Finally, I would like to thank those closest to me. I am forever grateful to my parents for their absolute confidence in me. Your guidance and enthusiasm offer the perfect balance between providing direction and encouraging independence. Most importantly, I thank Shaun, who has shown untiring patience and support, reminding me of my priorities and keeping things in perspective. Your unique way of seeing the world kept me optimist and made me happy.

For the errors that may have crept into this thesis, I alone am responsible.
The primary aim of this thesis was to investigate the gender-specific responses to supramaximal cycling and to examine the changes in anaerobic and aerobic metabolism that occur in response to high-intensity interval training (HIT). All subjects in the present experiments were untrained, healthy young adults aged between 18 and 35 yr. Cycle ergometry was used for all experimental test procedures and training programs. The accumulated oxygen (AO$_2$) deficit was used to quantify the production of adenosine triphosphate (ATP) via anaerobic metabolism during supramaximal cycling. In addition, pulmonary oxygen uptake ($\text{VO}_2$) measured at the onset of exercise was described using mathematical modeling to determine the rate response of the aerobic energy system during exercise.

The purpose of experiment one was to examine the test-retest reliability of the maximal accumulated oxygen deficit (MAOD) measured at 110% and 120% of peak
oxygen uptake (\(\bar{V}O_2\)peak) for cycling in seven untrained male and seven untrained female subjects. After one familiarization trial, all subjects performed two MAOD tests at a power output corresponding to 110% and two tests at 120% of \(\bar{V}O_2\)peak in random order. MAOD was calculated for each subject as the difference between the estimated \(AO_2\) demand and the \(AO_2\) uptake measured during the exercise bout. The mean±standard error time to exhaustion (TE) for the group was not significantly different between trial one (226±13 s) and trial two (223±14 s) of the 110% test. Likewise, the difference in the TE between trial one (158±11 s) and trial two (159±10 s) was not significant for the 120% test. The intra-class correlation coefficients for the TE were 0.95 for the 110% test and 0.98 for the 120% test. The mean MAOD value obtained in trial one (2.62±0.17 L) was not significantly different from the mean value obtained in trial two (2.54±0.19 L) for the 110% test. Additionally, the mean values for the two trials did not differ significantly for MAOD (2.64±0.21 L for trial one and 2.63±0.19 L for trial two) in the 120% test. The intra-class correlation coefficients for MAOD were 0.95 for the 110% test and 0.97 for the 120% test. All intra-class correlation coefficients were significant at \(p < 0.001\). When conducted under standardized conditions, the determination of MAOD for cycling was highly repeatable at both 110% and 120% of \(\bar{V}O_2\)peak in untrained male and female subjects.

The results observed in experiment one suggest that the MAOD may be used to compare the anaerobic capacity (AC) of men and women and to examine changes in the contribution of the anaerobic energy systems before and after training. Experiment two examined the gender-specific differences in MAOD before and after 4 and 8 wk of HIT. Untrained men (n=7) and women (n=7) cycled at 120% of pre-training \(\bar{V}O_2\)peak to exhaustion (MAOD test) pre-, mid-, and post-training. A post-training timed test was also completed at the MAOD test power output, but this test was stopped at the TE achieved during the pre-training MAOD test. The 14.3±5.2% increase in MAOD observed in males after 4 wk of training was not different from the 14.0±3.0% increase seen in females (\(p > 0.05\)). MAOD increased by a further 6.6±1.9% in males and this change was not different from the additional 5.1±2.3% increase observed in females after the final 4 wk of training. Peak \(\bar{V}O_2\) measured during incremental cycling increased significantly (\(p < 0.01\)) in male but not in female
subjects after 8 wk of training. Moreover, the AO₂ uptake was higher in men during the post-training timed test compared to the pre-training MAOD test (p < 0.01). In contrast, the AO₂ uptake was unchanged from pre- to post-training in female subjects. The increase in MAOD with training was not different between men and women suggesting an enhanced ability to produce ATP anaerobically in both groups. However, the increase in VO₂peak and AO₂ uptake obtained in male subjects following training indicates improved oxidative metabolism in men but not in women. It was concluded that there are basic gender differences that may predispose males and females to specific metabolic adaptations following an 8-wk period of HIT.

Increases in AO₂ uptake during supramaximal cycling demonstrated in men after training led to the hypothesis that VO₂ kinetics are speeded in male subjects with short-term HIT. It was suggested that training does not improve VO₂ kinetics in women as no change in AO₂ uptake was found after 8 wk of HIT in female subjects. The purpose of experiment three was to examine VO₂ kinetics before and after 8 wk of HIT in six men and six women during cycling at 50% (50% test) and 110% (110% test) of pre-training VO₂ peak. A single-term exponential equation was used to model the VO₂ response (after phase I) during the 50% and 110% tests pre- and post-training. In addition, phase II and III of the VO₂ response during the 110% tests were examined using a two-term equation. The end of the phase I VO₂ response was identified visually and omitted from the modeling process. The duration of phase I determined during all experimental tests was not different between men and women and did not change with training in either group. Before training, men obtained a phase II VO₂ time constant (τ₂) of 29.0±3.3 s during the 50% test which was not different to the τ₂ of 28.8±2.2 s attained by women. In addition, the τ₂ determined during the 50% test was unchanged after 8 wk of HIT in both groups. The VO₂ kinetics examined during the 110% tests before training were well described by a single-term model in all male and female subjects. The τ₂ determined before training for the 110% test was significantly faster in men than in women. Furthermore, VO₂peak was unchanged in female subjects and the τ₂ remained unaltered with 8 wk HIT (pre 45.5±2.2; post 44.8±2.3 s). In contrast, male subjects achieved a significantly higher VO₂peak after training and the τ₂ determined for men during the 110% test was faster after training (36.4±1.6 s) than before training (40.1± 1.9 s).
Improved model fits were obtained with the two-term equation compared to the single-term equation in two of the six male subjects during the 110% test post-training. It was found that the onset of the $\dot{V}O_2$ slow component occurred at a mean time of $63.5\pm2.5$ s and the $\tau_2$ was reduced to $18.4\pm1.7$ s. Using a Wilcoxon Signed Ranks z-test, the $\tau_2$ described by the single-term equation in the remaining four subjects was determined to be significantly faster after training than before training, thus confirming the results obtained from the original group ($n=6$) of male subjects. End exercise heart rate (HREE) values obtained during the 50% and 110% tests were not different between men and women. During the 50% test, HREE values were unchanged, whereas HREE was significantly decreased during the 110% test after training in both groups. These data show that HIT might improve oxidative metabolism in men but not in women as reflected by a greater $\dot{V}O_2$ peak and faster $\dot{V}O_2$ kinetics during supramaximal work rates. We further suggest that the faster $\dot{V}O_2$ kinetics demonstrated in men after training are probably not due to an improvement in cardiac function. Finally, the augmentation of oxidative metabolism during exercise after HIT in men might be dependent on the intensity of the exercise bout at which the $\dot{V}O_2$ response is examined.

The findings presented in this thesis suggest that MAOD is a reliable measure in both male and female subjects and can be used to monitor changes in anaerobic ATP production during supramaximal cycling. Moreover, these data suggest that 4 and 8 wk of HIT produce similar changes in anaerobic ATP generation in men and women. Finally, 8 wk of HIT results in the increase of $\dot{V}O_2$ peak and $AO_2$ uptake as well as the speeding of $\dot{V}O_2$ kinetics during supramaximal cycling in male subjects. There was no evidence to suggest that oxidative metabolism was improved in women after short-term HIT. In conclusion, improvement in supramaximal exercise performances should be examined specifically for changes in the anaerobic and aerobic contributions to energy production. In addition, it is suggested that gender should be of primary consideration when designing exercise-training programs where improvement in both anaerobic and aerobic metabolism is required.
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