PHYSIOLOGICAL AND PERFORMANCE EFFECTS OF ALTITUDE TRAINING AND EXPOSURE IN ELITE ATHLETES

A thesis submitted in fulfilment of the requirements for the degree of
Doctor of Philosophy
of the University of Canberra

Eileen Y. Robertson

MSc (Research) Sports Studies, University of Stirling, 2005
MSci Physiology & Sports Science, University of Glasgow, 2002

August, 2009

ABSTRACT

Despite widespread popularity of altitude training with athletes and coaches, and extensive research over the last 50 years, the transfer of improvements in physiological capacities to competitive performance remains uncertain. This thesis quantified the magnitude of performance gains required to improve placing in international competition, and the performance enhancements and physiological adaptations that can be obtained from altitude training and exposure in elite swimmers and runners.

Performance gains of ~1% will substantially increase the chance of a medal in elite swimmers. This was quantified by a novel analysis of the relationships between lap time and performance, which combined between-athlete correlations and within-athlete effects. Overall, the final lap for 100-m events and the middle two laps for 200-m and 400-m events had the strongest relationship (r~0.7-0.9) with final time. A change in these laps was associated with ~0.4-0.8% improvement in final time for finalists, and ~0.5-1.1% for semi-finalists, depending on sex, stroke and event. However, a similar pattern of lap times was adopted in each event regardless of the sex, finish position, or the best and worst swims for an individual. To gain a competitive advantage, many athletes employ some form of altitude training in an attempt to elicit small enhancements in performance.

Three to four repeated 2-wk blocks of living and training at natural altitude (1350 m) and/or simulated live high/train low exposure (LHTL, 2600 m, 9-10 $h \cdot d^{-1}$) were undertaken by elite swimmers (n=9). Each 2-wk block produced the following mean improvements: haemoglobin mass (Hb_{mass}), 0.9% (±0.8%, 90% confidence limits); 4-mM lactate threshold velocity, 0.9% (±0.8%); 2-km time-trial performance, 1.2% (±1.6%). There was no substantial improvement in competition performance compared with swimmers (n=9) who received no altitude exposure (altitude-control: 0.5%; ±1.0%). To gain substantial enhancements in physiological and performance capacities, a more effective model of altitude training is required.

The final two studies employed 3-wk bouts of simulated LHTL (3000 m, 14 $h \cdot d^{-1}$) in well-trained runners. The test-retest reliability of responses to 2 x 3-wk LHTL were quantified, with reproducible increases in Block 1 and 2 for $\dot{V}O_{2max}$ (2.1%; ±2.1% and 2.1%; ±3.9%) and Hb_{mass} (2.8%; ±2.1% and 2.7%; ±1.8%), but 4.5-km time-trial performance was more variable (-1.4%; ±1.1%, faster and 0.7%; ±1.3%, slower) in the LHTL group (n=8). Compared with

the control group (n=8) who had only trivial changes, the LHTL group were substantially faster after Block 1 (LHTL-control: -1.9%; ±1.8%), had higher Hb_{mass} after Block 2 (4.2%; ±2.1%), but a trivial difference in change in $\dot{V}O_{2max}$ after each 3-wk block. It appears that physiological responses to altitude are reproducible, but transfer to improved time-trial performance is more variable.

Finally, the effect of 3 weeks of intermittent hypoxic training (TH, 2200 m, $4 \cdot wk^{-1}$) or combined LHTL plus TH (LH/TL+TH) were examined. The LH/TL+TH group (n=8) substantially improved $\dot{V}O_{2max}$ (4.8%; ±2.8%), Hb_{mass} (3.6%; ±2.4%) and 3-km time-trial performance (-1.1%; ±1.0%); while the TH group (n=9) improved $\dot{V}O_{2max}$ (2.2%; ±1.8%), but had only trivial changes in Hb_{mass} and time trial. The LH/TL+TH group had substantially higher Hb_{mass} (4.3%; ±3.2%), however, the small increase in $\dot{V}O_{2max}$ (2.6%; ±3.2%) and trivial improvement in time trial performance (-0.9%; ±1.4%) became unclear when adjusted for differences in training ($\dot{V}O_{2max}$: 0.8%; ±3.5% and time trial: -0.3%; ±1.5%). LH/TL+TH was a potent stimulator for improvements in physiological measures, but transfer of these improvements to time-trial performance was limited.

A structured program of 3-wk simulated LHTL, with or without additional hypoxic training, can elicit substantial improvements in $\dot{V}O_{2max}$ and Hb_{mass} and enhance time trial performance by ~1% in well-trained athletes. Evidence of individual responses indicates some athletes respond more favourably than others, and the degree of within-athlete variation to repeated bouts indicates altitude training should be managed carefully in the context of other training and competition. Altitude training and exposure can enhance physiological capacities, but further research is required to improve the direct transfer of these benefits to competitive performance.

CERTIFICATE OF AUTHORSHIP OF THESIS

Except where clearly acknowledged in footnotes, quotations and the bibliography, I certify that I am the sole author of the thesis submitted today entitled:

Physiological and performance effects of altitude training and exposure in elite athletes

I further certify that to the best of my knowledge the thesis contains no material previously published or written by another person except where due reference is made in the text of the thesis.

The material in the thesis has not been the basis of an award of any other degree or diploma except where due reference is made in the text of the thesis.

The thesis complies with University requirements for a thesis as set out in

http://www.canberra.edu.au/secretariat/goldbook/forms/thesisrqmt.pdf

Signature of Candidate: .....

Signature of chair of the supervisory panel: .....

Date: .....

ACKNOWLEDGEMENTS

I would like to take the opportunity to acknowledge the following people who have offered help and encouragement throughout my PhD candidature and this thesis.

Firstly, I wish to express my gratitude to my primary supervisor, Professor David Pyne (Australian Institute of Sport, AIS), for his intellectual input and guidance throughout this research. His knowledge and mentoring have been integral in developing my skills as a researcher and for completion of this thesis.

I would like to thank my academic supervisor, Dr Judith Anson (University of Canberra) for her advice and detailed feedback, particularly in relation to manuscript and thesis preparation.

I would like to acknowledge the senior physiologists, technical staff and students of the Department of Physiology at the AIS for support and assistance in data collection. I have thoroughly enjoyed the friendship of my AIS colleagues and the opportunity to work with such a wonderfully enthusiastic team. Particular thanks must go to Professor Chris Gore and Dr Philo Saunders who through their passion for the performance and physiological responses to altitude have given me invaluable insight into a heavily researched field.

Thank you to my former supervisor from the University of Canberra, Dr Rob Aughey (Victoria University), for his early input and collaboration on one of the studies.

I would like to express thanks to Professor Will Hopkins (Auckland University of Technology) for his expert assistance and guidance in statistical analysis and interpretation of meaningful changes throughout this thesis.

Thank you to all the subjects that participated in the experimental trials, without their commitment and effort the research in this thesis would not have been possible.

A special mention to Marilyn Dickson and Gavin, whose endless generosity, warmth and kindness has supported their ‘wee Scottish lass’ during her time in Canberra.

Finally, thank you to my family and friends who have offered support, encouragement and understanding throughout my candidature.

PUBLICATIONS AND PRESENTATIONS BY THE CANDIDATE RELEVANT TO THE THESIS

Publications Arising From This Thesis:

Robertson, E.Y., D.B. Pyne, W.G. Hopkins, and J. Anson. Analysis of lap times in international swimming competitions. *Journal of Sports Science*. 27 (4): 387-395, 2009.

Robertson, E.Y., R.J. Aughey, J. Anson, W.G. Hopkins, and D.B. Pyne. Effects of simulated and real altitude exposure in elite swimmers. *Journal of Strength and Conditioning Research*. 23: (in press), 2009.

Robertson, E.Y., P.U. Saunders, D.B. Pyne, R.J. Aughey, J. Anson, and C.J. Gore. Reproducibility of performance changes to simulated live high/train low altitude. *Medicine and Science in Sports and Exercise*. 42: (in press), 2010.

Robertson, E.Y., P.U. Saunders, D.B. Pyne, J. Anson, and C.J. Gore. Effectiveness of intermittent training in hypoxia combined with live high/train low. *European Journal of Applied Physiology.* (to be submitted).

Aughey, R.J., N.S. Stepto, F. Serpiello, **E.Y. Robertson**, P.U. Saunders, D.B. Pyne, and C.J. Gore. HIF-1α response to repeated bouts of live high:train low altitude. (in preparation).

Peer Reviewed Conference Proceedings:

E.Y. Robertson, P.U. Saunders, D.B. Pyne, C.J. Gore, and J. Anson. Effectiveness of intermittent training in hypoxia combined with live high/train low. *Proceedings of the 14th Annual Congress of the European College of Sport Science*. Abstract 1575, p. 146, 2009.

E.Y. Robertson, P.U. Saunders, D.B. Pyne, R.J. Aughey, J. Anson, and C.J. Gore. Reproducibility of performance gains to simulated Live High/Train Low altitude. *Proceedings of the 13th Annual Congress of the European College of Sport Science*. Abstract 2348, p. 141, 2008.

E.Y. Robertson, D.B. Pyne, W.G. Hopkins and J. Anson. Pacing strategies of successful swimmers in international competitions. *Journal of Science and Medicine in Sport*. 10(6) Supplement: p. 16, 2007.

Conference Presentations:

Congress of the European College of Sport Science, Norway 2009.

E.Y. Robertson, P.U. Saunders, D.B. Pyne, C.J. Gore, and J. Anson. "Effectiveness of intermittent training in hypoxia combined with live high/train low".

Congress of the European College of Sport Science, Portugal 2008.

E.Y. Robertson, P.U. Saunders, D.B. Pyne, R.J. Aughey, J. Anson, and C.J. Gore. "Reproducibility of performance gains to simulated Live High/Train Low altitude".

Sports Medicine Australia, Adelaide 2007.

E.Y. Robertson, D.B. Pyne, W.G. Hopkins and J. Anson. "Pacing strategies of successful swimmers in international competitions".

Applied Physiology Conference, Sydney 2006.

E.Y. Robertson, R.J. Aughey, J. Anson, W.G. Hopkins and D.B Pyne. "Effects of simulated and real altitude exposure in elite swimmers: A field study".

DECLARATION

This dissertation summarises original work conducted in the Department of Physiology, Australian Institute of Sport, Canberra. This thesis includes research papers for which I am the senior but not the sole author. I took the lead in this research in terms of experimental design, data collection and analysis, and wrote the manuscripts. I was, however, assisted by my co-authors. The research papers which appear as Chapters Three, Four, Five and Six were prepared through substantial, independent contribution by the senior author. Co-authors are listed at the start of each Chapter. Collaborators on the study which appears as Chapter Five, are currently undertaking analysis of additional blood samples collected during the main study and taking the lead on manuscript preparation. Preliminary findings are presented, with details of the working title and list of co-authors for the manuscript, in Appendix 2.

Eileen Y. Robertson

DEDICATION

To my parents Evelyn and Sandy Robertson

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER SIX

CHAPTER SEVEN

LIST OF FIGURES

CHAPTER TWO

CHAPTER THREE

CHAPTER FOUR

CHAPTER FIVE

CHAPTER SIX

LIST OF APPENDICES