The Acute Physiological, Physical and Perceptual Responses to Intermittent Hypoxic Resistance Training

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Statement of Originality

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We, Ben Dascombe, Katie Slattery and Dean Sculley, attest that the research completed within this thesis by the candidate Brendan Scott, was completed in collaboration with the following organisation:

- New South Wales Institute of Sport, Sydney

Supervisor: Ben Dascombe (PhD)	21 / 08 / 2015 Date Signed
Supervisor: Katie Slattery (PhD)	21 / 08 / 2015 Date Signed
Supervisor: Dean Sculley (PhD)	21 / 08 / 2015 Date Signed

Acknowledgement of Authorship

I hereby certify that the work embodied in this thesis contains a published paper/s/scholarly work of which I am a joint author. I have included as part of the thesis a written statement, endorsed by my supervisor, attesting to my contribution to the joint publication/s/scholarly work.

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We, Ben Dascombe, Katie Slattery and Dean Sculley, attest that Research Higher Degree candidate Brendan Scott was a contributor to the conception, design, writing and revision of the previously mentioned publications.

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List of Publications Arising From This Thesis

Peer-reviewed articles:

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Scott, B. R., Loenneke, J. P., Slattery, K. M., & Dascombe, B. J. (2015). Exercise with blood flow restriction: an updated evidence-based approach for enhanced muscular development. *Sports Medicine*, 45 (3), 313-325.

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Scott, B. R., Slattery, K. M., Sculley, D. V., Hodson, J. A., & Dascombe, B. J. (2015). Physical performance during high-intensity resistance exercise in normoxic and hypoxic conditions. *Journal of Strength and Conditioning Research,* 29(3), 807-815.

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Conference Proceedings:

Scott B. R., Slattery K. M. and Dascombe B. J. (2014) Metabolic and neuromuscular responses to high-load intermittent hypoxic resistance training. *ASCA International Conference on Applied Strength and Conditioning.* Melbourne, Australia.

- Winner of the ASCA Student Poster Award

Scott, B. R., Slattery, K. M., Taylor, L., & Dascombe, B. (2014). Physical performance and perception of effort, fatigue and soreness during high-intensity resistance exercise in hypoxia*. 6th Exercise & Sports Science Australia Conference & Sports Dietitians Australia Update: Research to Practice*. Adelaide, Australia.

- Finalist for the University of Western Australia Poster Award

Scott, B. R., Delaney, J. A., Elsworthy, N., & Dascombe, B. (2013). The reliability of a linear position transducer to quantify measures of force and power during resistance exercise. *Australian Conference of Science and Medicine in Sport*. Phuket, Thailand.

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List of Abbreviations

~	Approximately
>	Greater than
≥	Greater than or equal to
<	Less than
≤	Less than or equal to
↑	Increase
↓	Decrease
↔	No change
?	Equivocal or unclear findings
±	Plus/minus
%	Percent
°	Degree/s
$°\cdot s^{-1}$	Degrees per second
°C	Degrees Celsius
µL	Microlitre
η^2	eta squared
Δ	Delta
1RM	1-Repetition maximum
10RM	10-Repetition maximum
ANOVA	Analysis of variance
ATP	Adenosine triphosphate
AU	Arbitrary units
BF	Biceps femoris
BFR	Blood flow restriction
BLa^-	Blood lactate
$[BLa^-]$	Blood lactate concentration

bpm	Beats per minute
CI	Confidence intervals
cm	Centimetre
CMJ	Countermovement jump
CR-10	Category-Ratio 10 scale
CSA	Cross-sectional area
CV	Coefficient of variation
EMG	Electromyography
ES	Effect size
F	*F* statistic
F_IO_2	Fraction of inspired oxygen
GH	Growth hormone
GM	Gluteus maximus
h	Hour/s
H^+	Hydrogen ion
HbO_2	Oxyhaemoglobin
HbO_{2min}	Relative minimum oxyhaemoglobin value
$[HbO_2]$	Oxyhaemoglobin concentration
HBS	Harness back squat
HH	High-level hypoxia
HHb	Deoxyhaemoglobin
HHb_{max}	Relative maximum deoxyhaemoglobin value
[HHb]	Deoxyhaemoglobin concentration
HIF-1α	Hypoxia-inducible factor-1α
HR	Heart rate
Hz	Hertz
ICC	Intra-class correlation coefficient
iEMG	Integrated electromyography

IGF-1	Insulin-like growth factor-1
IHRT	Intermittent hypoxic resistance training
kg	Kilogram/s
m	Metre/s
MAPK	Mitogen-activated protein kinase
MDF	Median frequency of the electromyography signal
MH	Moderate-level hypoxia
min	Minute/s
mm	Millimetre/s
mmHg	Millimetres of mercury
$mmol \cdot L^{-1}$	Millimole per litre
MPS	Muscle protein synthesis
mRNA	Messenger ribonucleic acid
$m \cdot s^{-1}$	Metres per second
mTOR	Mammalian target of rapamycin
MTP	Mid-thigh pull
MVC	Maximum voluntary contraction
MVC_3	Maximum voluntary contraction for 3 seconds
MVC_{30}	Maximum voluntary contraction for 30 seconds
n	Number
N	Newtons
NIRS	Near-infrared spectroscopy
nm	nanometer
NORM	Normoxia
O_2	Oxygen
p	Alpha
PCr	Phosphocreatine
pH	Potential hydrogen

P_i	Inorganic phosphate
PO_2	Partial pressure of oxygen
r	Pearson's correlation coefficient
r^2	Pearson's *r* squared
reps	Repetitions
RFD	Rate of force development
RMS	Root mean square of electromyography signal
RNA	Ribonucleic acid
ROS	Reactive oxygen species
RPE	Rating of perceived exertion
RT	Resistance training without BFR in normoxia
s	Second/s
SD	Standard deviation of the mean
SENIAM	Surface EMG for non-invasive assessment of muscles
SJ	Squat jump
sO_2	Oxygen saturation
SpO_2	Arterial oxygen saturation (%)
sRPE	Session rating of perceived exertion
S6K1	Ribosomal S6 kinase 1
TSI	Tissue saturation index
TSI_{min}	Relative minimum tissue saturation index
VEGF	Vascular endothelial growth factor
VL	Vastus lateralis
VM	Vastus medialis
W	Watts
$W \cdot kg^{-1}$	Watts per kilogram
WU	Warm-up set
yr	Year/s

Abstract

Recent evidence suggests that supplemental hypoxia during resistance training can enhance muscular adaptation. However, the mechanisms underpinning augmented muscular responses to intermittent hypoxic resistance training (IHRT) and how they can be optimised remain largely unknown. Therefore, the aim of this thesis was to examine the acute physiological, physical and perceptual responses to IHRT in well-trained participants.

Study 1 quantified the inter- and intra-test reliability of electromyography (EMG) and near-infrared spectroscopy (NIRS) technologies during resistance exercise. Twelve well-trained young men (age: 24.8 ± 3.4 yr; height: 178.6 ± 6.0 cm; body mass: 84.8 ± 11.0 kg) performed high-load back squat exercise (12 sets at 70-90% of 1-repetition maximum [1RM]) on two occasions, with thigh muscle activation and oxygenation being monitored by EMG and NIRS, respectively. Intra-test reliability for EMG and NIRS variables was generally higher than inter-test reliability. NIRS-derived measures of muscle oxygenation were generally more reliable during single-repetition sets than multiple-repetition sets at the same load. Although the reliability of EMG and NIRS varied across the exercise protocol, the biological variation during multi-joint isoinertial resistance exercise may account for the fluctuations in the observed results.

Study 2 aimed to determine whether different levels of hypoxia affect physical performance during high-load resistance exercise. Using a randomised single

blind cross-over design, 12 resistance-trained males (age: 25.3 ± 4.3 yr; height: 179.0 ± 4.5 cm; body mass: 83.4 ± 9.1 kg) completed three trials of 5 x 5 repetitions of back squats and deadlifts at 80% 1RM with 180 s inter-set rest. Trials took place in normoxia (NORM; fraction of inspired oxygen [F_IO_2] = 21%), moderate-level hypoxia (MH; F_IO_2 = 16%), and high-level hypoxia (HH; F_IO_2 = 13%). Physical performance was monitored during repetitions (force and power variables), and arterial oxygen saturation (SpO_2), heart rate (HR), and a rating of perceived exertion (RPE) were obtained following each set. No differences in performance were evident between conditions. HR was higher following sets in HH than NORM ($p = 0.009$), while SpO_2 was lower in hypoxic conditions than in NORM ($p < 0.001$). There were no differences in RPE between conditions. These findings suggest that physical performance and perceived effort during high-load resistance exercise is not affected by supplemental hypoxia.

Study 3 assessed whether hypoxia during high-load resistance exercise could enhance the acute responses thought to underpin IHRT adaptation. Twelve well-trained males (age: 25.3 ± 4.3 yr; height: 179.0 ± 4.5 cm; body mass: 83.4 ± 9.1 kg) performed the same high-load resistance exercise protocol described for Study 2 in NORM, MH and HH. Muscle oxygenation and activation were monitored via NIRS and EMG, respectively. Blood lactate (BLa^-) concentration and pH levels were assessed to quantify metabolic stress. Perceived fatigue and soreness were also quantified following the exercise. HH appeared to cause the lowest levels of muscle oxygenation during exercise, though significant differences between conditions were only observed for maximal

deoxyhaemoglobin in the deadlift ($p = 0.009$). Metabolic stress increased from baseline following exercise ($p \leq 0.004$), however there were no consistent between-condition differences. Muscle activation, perceived fatigue and soreness also did not differ between conditions. These data suggest that high-load IHRT may not provide added benefit over the equivalent normoxic training, possibly because of its inherent design with long inter-set rest periods.

Study 4 assessed whether moderate-load IHRT with short rest periods could augment acute anabolic responses. Using a randomised single blind cross-over design, 14 well-trained male subjects (age: 24.6 ± 2.7 yr; height: 179.7 ± 5.9 cm; body mass: 84.6 ± 11.6 kg) performed resistance exercise trials in NORM and MH (3 x 10 repetitions of back squats and deadlifts at 60% 1RM with 60 s rest). SpO_2 and HR were assessed following each set, and BLa^- concentration was quantified after each exercise. Thigh circumference was measured as a marker of muscle swelling. Muscle activation and oxygenation were monitored via EMG and NIRS, respectively. Relative BLa^- concentrations were significantly higher following both squats ($p = 0.041$) and deadlifts ($p = 0.002$) in MH than NORM. SpO_2 was lower following each set in MH ($p < 0.001$), though there were no between-condition differences for HR or thigh circumference. Integrated EMG was higher in the MH trial at several time points for the back squat ($p < 0.001$), but not the deadlift. Muscle oxygenation did not differ between conditions. These data demonstrate that hypoxia during moderate-load resistance exercise with brief rest periods between sets can enhance metabolic stress in concert with increased muscle activation.

Lastly, Study 5 aimed to determine whether hypoxia can affect markers of physical performance, training stress and neuromuscular recovery during moderate-load resistance exercise. Fourteen well-trained male subjects (age: 24.6 ± 2.7 yr; height: 179.7 ± 5.9 cm; body mass: 84.6 ± 11.6 kg) performed the same moderate-load resistance exercise protocol as for Study 4 in NORM and MH. Physical performance was quantified during repetitions (velocity and power). Perceived exertion, fatigue, soreness and wellbeing were assessed during and following exercise. Neuromuscular performance was monitored using vertical jump and isometric mid-thigh pull (MTP) tasks for up to 48 h following exercise. Performance declined across sets ($p \leq 0.010$), though this was not different between conditions. Perceptual responses were also not different between conditions. Jump height and MTP peak force were decreased from pre-exercise values immediately after all trials ($p \leq 0.026$), but returned to pre-exercise values at 24 h. Despite increases in metabolic stress and muscle activation (Study 4), physical performance and markers of training stress were not impacted by hypoxia during moderate-load resistance exercise.

This collective work has highlighted the importance of structuring exercise using sufficient repetition volume and brief inter-set rest periods to elicit hypoxia-mediated benefits. Moderate-load IHRT with short rest in hypoxia was shown to enhance metabolic stress and muscle activation, which may maximise adaptation to resistance training. Importantly, supplementary hypoxia did not affect markers of training stress or recovery of neuromuscular function, making this an attractive strategy for already well-trained individuals.