A Comparison of VO₂, and Muscle and Prefrontal Cortex Tissue Oxygen Extraction between Short and Long-term Aerobically Trained Men Aged 40 - 60 Years

GAvin BuzzA*†, GEOFF P. Lovell‡2,3, CHRISTOPHER D. Askew‡4, and COLIN Solomon‡4

1School of Exercise Science, Sport, and Health, Charles Sturt University, Port Macquarie, AUSTRALIA; 2School of Social Sciences, University of the Sunshine Coast, Sippy Downs, AUSTRALIA; 3Department of Sport, Hartpury University, Hartpury, UNITED KINGDOM; 4School of Health and Sport Sciences, University of the Sunshine Coast, Sippy Downs, AUSTRALIA

*Denotes undergraduate student author, †Denotes graduate student author, ‡Denotes professional author

ABSTRACT

International Journal of Exercise Science 13(3): 964-978, 2020. This study was designed to compare systemic O₂ utilization (VO₂), and changes in tissue O₂ extraction [deoxyhemoglobin (ΔHHb)] in the vastus lateralis (VL), gastrocnemius (GAST) and pre-frontal cortex (PFC) tissue; between aerobically short-term trained (STT) and long-term trained (LTT) older men (40 - 60 yr) who were matched for current training load. On separate occasions, 14 STT and 14 LTT participants completed ramp incremental (RI) and square-wave constant load (SWCL) tests on a cycle ergometer. In LTT compared to STT; (i) VO₂ was higher during the RI (p > 0.001) and SWCL (p > 0.001) tests, (ii) ΔHHb in the GAST was greater in SWCL (p = 0.011); and (iii) ΔHHb in the PFC was greater at 90% GET during SWCL (p = 0.011). The additional years of training in LTT compared to STT (LTT 17.50yr ± 6.94yr vs STT 1.68yr ± 0.31yr) were associated with higher VO₂peak, and sub- GET VO₂, and ΔHHb in the GAST and PFC at sub- GET exercise, despite there being no difference in current training volume.

KEY WORDS: Older men, aerobic training, VO₂peak, oxygenation.

INTRODUCTION

Regular aerobic exercise training increases peak oxygen uptake (VO₂peak) in previously untrained adults irrespective of age and sex (6, 34). While the rate and magnitude of the increases in VO₂peak depend largely on the training load (intensity and volume) of the intervention (18, 47), gains in VO₂peak plateau within ~ 24 months (27, 46). The effect of many years of aerobic training on VO₂peak is limited to longitudinal studies (7 - 20 yr) investigating how age-related declines in VO₂peak are offset with regular aerobic training (17, 30); where the rate of decline is strongly related to changes in training volume over time (11, 23). If training volume is the primary mediator of increases in VO₂peak, then the training length (years of
training) should not affect VO$_{2\text{peak}}$ if the training volume is matched. Currently, differences in VO$_{2\text{peak}}$ between short and long-term trained individuals of the same age and current training volume is limited to one study from our laboratory on women aged 40 - 60 yr (8). However, as training volumes were significantly different between the women in that study and the men in the present study, and age-related declines in VO$_{2\text{peak}}$ differ between sexes (17, 53), a direct comparison could not be made. A unique finding in the study of older women (8) was that higher pulmonary ventilation ($V_{E}$) in the LTT at peak exercise resulted from an increase in tidal volume ($V_{T}$) not breathing frequency (BF) as previously reported (49). Whether the same applies to older men is unknown.

Increases in VO$_{2\text{peak}}$ from aerobic training result from enhanced O$_{2}$ delivery (from increased peak cardiac output and vascular volume) and/or O$_{2}$ extraction by active muscles (producing an increase in peak arterio-venous O$_{2}$ difference). The relative contribution that each component has on increases in VO$_{2\text{peak}}$ differ between young and older men (35, 37). In healthy older men, based on variable responses (32, 33), the relative contribution that central and peripheral adaptations have on changes in VO$_{2\text{peak}}$ are less clear. Furthermore, while an increased arterio-venous O$_{2}$ difference is strongly linked to muscle tissue O$_{2}$ extraction, changes in arterio-venous O$_{2}$ difference reflect O$_{2}$ extraction of all tissues of the body, not isolated active muscles.

While peak or max values are commonly used to indicate an individual’s exercise capacity, longer bouts of submaximal exercise (below GET) are typically performed in training and competition. Moreover, endurance training can affect O$_{2}$ kinetics and the matching of O$_{2}$ delivery to utilization during transitions from low to moderate intensity cycling in older men (2, 36), with greater improvements in long-term compared to short-term trained men (21). This adaptation could be due, in part, to an increased affinity of O$_{2}$ to hemoglobin and a decrease in blood lactate for a given intensity (51), which could improve O$_{2}$ delivery and extraction at the muscle tissue during longer periods of moderate intensity exercise. However, while short term (4 wks) endurance training does not affect HHb amplitude or pattern during longer duration (15 min) constant load cycling (10), the effect of long-term training is not known.

Near-infrared spectroscopy (NIRS) provides a non-invasive indirect method of measuring real time changes in O$_{2}$ extraction in isolated tissue via changes in deoxygenated hemoglobin (HHb) and oxyhemoglobin (O$_{2}$Hb) (15, 22), with the HHb signal representing microvascular O$_{2}$ extraction (balance between O$_{2}$ delivery and utilization), and thus being indicative of arterio-venous O$_{2}$ difference (12, 20). Previous studies have used the rate of response of HHb (normalised to peak HHb) during transitions from low to moderate exercise to report training induced improvements in active muscle tissue O$_{2}$ extraction in men (21, 36). However, changes in HHb ($\Delta$HHb) at peak exercise would provide an indication of the peak dynamic balance between O$_{2}$ supply and demand, as total leg O$_{2}$ extraction capacity is related to VO$_{2\text{peak}}$ (40, 44). Furthermore, some research indicates a link between cerebral (prefrontal cortex [PFC]) oxygenation and maximal exercise performance (4, 41), with greater oxygenation in trained and untrained individuals (45). While training length in years has no effect on the PFC oxygenation in women 40 - 60 yr (8) during low and high intensity exercise, the effect on men > 40 years is currently unclear.
The purpose of this study was to simultaneously investigate systemic O\textsubscript{2} utilization (VO\textsubscript{2}), and tissue O\textsubscript{2} extraction (\(\Delta\)HHb) in two active muscles and the PFC between STT (6 - 24 months) and LTT (> 5 years) aerobically trained men aged 40 - 60 years matched for current training load, during ramp incremental (RI) and sub-gas exchange threshold (GET) square-wave constant load (SWCL) cycling. It was hypothesized that: 1) VO\textsubscript{2} and \(\Delta\)HHb in the vastus lateralis (VL) and gastrocnemius (GAST) would be greater in LTT compared to STT at 90% GET, GET and peak exercise during RI, and all measured relative intensities (25%, 80% and 90% GET) during SWCL cycling; and 2), that there would be no difference in the \(\Delta\)HHb in the PFC between the groups at any exercise intensity.

**METHODS**

*Participants*

The two participant groups of older (40 - 60 yr) Caucasian men consisted of one group of 14 short-term trained (STT; 6 - 24 months) men, and one group of 14 long-term trained (LTT; > 5 yr) men. Each participant had regularly completed > 230 min of moderate to vigorous aerobic exercise per week (all including cycling) missing no more than two weeks of training over any six-month period, as determined from self-reported physical activity training logs (refer Table 1). Current training load was determined by summing the product of each training session duration (min) and the intensity (1 = low, 2 = moderate, 3 = high) for the past week. All participants reported this training volume as a typical week of training completed within the previous six months. Participants’ physical characteristics and training history are provided in Table 1. Following medical screening (Physical Activity Readiness Questionnaire (7) and Medical Health Questionnaire), exclusion included any health related issues or medications that would affect participant safety and or exercise capacity or O\textsubscript{2} utilization/extraction.

*Protocol*

Session 1: The aim of session one was to determine participant characteristics, and VO\textsubscript{2}, ventilation (\(V_{\text{E}}\), \(V_{\text{T}}\), BF), HR, RPE (Table 2) and \(\Delta\)HHb in the VL, GAST and PFC during a RI cycling (increments = 1 W per 2 s) test to volitional cessation, as previously described (8). To encourage peak results, participants received feedback and encouragement from the tester during the RI test. Expired gas was analyzed (Parvo Medics, Sandy, UT, USA) to determine \(V_{\text{O2peak}}\), and GET, with \(V_{\text{O2peak}}\) determined as the highest 15-s average VO\textsubscript{2} value within the last minute of the RI test, and GET determined using the V-slope method as described by Beaver, Wasserman and Whipp (3). The V-slope method has been reported to be more accurate and have smaller standard deviations compared to other methods (19). The GET in the present study was time matched with the power (Watts) of the cycle ergometer to determine the power outputs for the SWCL test. As systemic VO\textsubscript{2} and muscle O\textsubscript{2} extraction were not directly compared (i.e. VO\textsubscript{2} to \(\Delta\)HHb ratio) and the RI and SWCL were not compared, VO\textsubscript{2} was not left shifted to accommodate for any potential phase 1-phase II VO\textsubscript{2} lag time.

Session 2: This session was conducted three to 14 days after session one. The aim of this session was to determine participants’ VO\textsubscript{2}, ventilation (\(V_{\text{E}}\), \(V_{\text{T}}\), and BF), HR, RPE (Table 4) and \(\Delta\)HHb while each participant cycled at the same calculated relative intensity of 25%, 80% and 90% of
GET power output obtained from the RI test. The timing for these intensities were as follows: 3 minutes at 25%, 80% and 25%; 20 minutes at 90%; and another 3 minutes at 25% of calculated GET.

VO₂, HR and ΔHHb in the VL, GAST and PFC were recorded continuously during exercise, while RPE was recorded within the last 10-s of the third minute of each of the three minute SWCL stages, and every fourth minute within the 20 minute stage using standard methods as previously described (8). To minimize cognitive stimulus, participants did not receive encouragement or feedback during this test.

Tissue Deoxyhemoglobin: Tissue oxygenation (HHb and O₂Hb) data were measured continuously and simultaneously from the left VL, GAST and PFC during exercise with a single-channel NIRS system (PortaMon and Portalite, Artinis Medical Systems BV, Zetten, Netherlands). The muscle optodes were fixed to the skin at the mid-belly of the muscle using adhesive tape and wrapped with low compression black elastic bandage, and the PFC optode was fixed to the skin at the left PFC using adhesive tape, then covered with a black headband (8).

All NIRS primary data (HHb and O₂Hb) were recorded at 10 Hz. The last 20-s of resting values were averaged to obtain baseline values. All changes were then expressed relative to these baseline values and then calculated and displayed as follows: 15-s averages for RI; 30-s averages for SWCL; total average data for the 15-s preceding 90% GET and peak exercise for RI; and total data for each exercise intensity for SWCL. In the present study, only HHb data have been presented, as compared to O₂Hb, HHb is less affected by changes in blood hemodynamics (12, 16), thus a better indicator of oxygen extraction.

### Table 1. Participant characteristics of the short-term trained and long-term trained older men.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>STT</th>
<th>LTT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>48.6 (5.5)</td>
<td>46.1 (4.6)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>87.4 (10.6)</td>
<td>79.9 (8.9)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>180.9 (7.5)</td>
<td>181.5 (6.2)</td>
</tr>
<tr>
<td>VL adipose (thickness)</td>
<td>5.7 (1.3)</td>
<td>4.9 (1.4)</td>
</tr>
<tr>
<td>GAST adipose (thickness)</td>
<td>3.4 (1.6)</td>
<td>3.3 (1.1)</td>
</tr>
<tr>
<td>Current training (yr)</td>
<td>1.7 (0.3)</td>
<td>17.5 (8.4) *</td>
</tr>
<tr>
<td>Lifetime training (yr)</td>
<td>7.6 (5.5)</td>
<td>17.5 (6.9) *</td>
</tr>
<tr>
<td>Current training load (AU)</td>
<td>1184 (420)</td>
<td>1242 (451)</td>
</tr>
<tr>
<td>GET VO₂ (mL·kg⁻¹·min⁻¹)</td>
<td>26.6 (5.5)</td>
<td>37.7 (5.4) *</td>
</tr>
<tr>
<td>GET % of Peak (mL·kg⁻¹·min⁻¹)</td>
<td>67.1 (8.0)</td>
<td>72.9 (5.0) *</td>
</tr>
</tbody>
</table>

Values are mean (SD).

* Significant (p < 0.05) difference between groups.

Current training (yr) = current number of continuous years of training; Current training load (AU) = min x intensity (light = 1, moderate = 2 and high = 3).

STT: Short-term trained; LTT: Long-term trained; VL: Left vastus lateralis; GAST: Gastrocnemius; AU: Arbitrary units; GET: Gas exchange threshold.
**Statistical Analysis**
All statistical analyses were performed using SPSS (version 22, SPSS Inc., Chicago, IL). Prior to statistical analysis, data were checked for normality using the Shapiro-Wilk test of normality and the Mauchly test for sphericity, and that the relevant assumptions for each test were met. To identify the presence of any significant group (STT vs LTT) differences in current training load, independent t-tests were conducted. To identify the presence of any significant exercise intensity and group (STT vs LTT) main effects or interactions, two-way Analysis of Covariance (ANCOVAs) were conducted on each dependent variable within each of the tests. For the RI, 2 (group: STT and LTT) x 2 (intensity: 90% of GET and peak) ANCOVAs were performed, and for the SWCL, 2 (group: STT and LTT) x 3 (intensity: 25% [first period of 25%] 80% and 90% of GET) ANCOVAs were performed. Due to the potential substantial effect of current training load on physiological responses to exercise, training load was included as a covariate in all analyses. For all analyses, the threshold for statistical significance was set to $p < 0.05$. Partial eta-squared was used to determine the effect size as small ($\eta_{{p}}^2 > 0.01$), medium ($\eta_{{p}}^2 > 0.06$) or large ($\eta_{{p}}^2 > 0.14$) as per Cohen (9).

**RESULTS**
Current training loads were not significantly different between STT and LTT (Table 1). For all dependent variables in both tests, there was a significant ($p < 0.05$) main effect of exercise intensity with a large effect size. These variables increased with increased exercise intensity, as physiologically expected (descriptive statistics are shown in Tables 2 and 3). Results for group main effects and group by intensity interactions are given in Table 4. There were significant ($p < 0.05$) group main effects for $\dot{V}O_2$ (mL·kg$^{-1}$·min$^{-1}$) and $V_E$ during both the RI and SWCL tests and $V_E$ during SWCL. There were significant ($p < 0.05$) group by intensity interactions for $\dot{V}O_2$ (mL·kg$^{-1}$·min$^{-1}$) and $V_E$ during the SWCL test. The difference in $\dot{V}O_2$ and $V_E$ between groups increased with increased intensity. The group mean $\Delta$HHb in the RI and SWCL tests are presented in Figures 1 and 2. There were significant ($p < 0.05$) group main effects for $\Delta$HHb in the GAST and PFC during the SWCL test. There were significant ($p < 0.05$) group by intensity interactions for $\Delta$HHb in the PFC during the SWCL test (Figures 3 and 4).

**Table 2.** Systemic oxygen utilization, ventilation, heart rate and rating of perceived exertion of short-term trained and long-term trained older men at 90% Gas Exchange Threshold and peak exercise during Ramp Incremental (RI) cycling.

<table>
<thead>
<tr>
<th>Variable</th>
<th>90% GET</th>
<th>Peak</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>STT</td>
<td>LTT</td>
</tr>
<tr>
<td>$\dot{V}O_2$ (mL·kg$^{-1}$·min$^{-1}$)</td>
<td>24.1 (3.6)</td>
<td>34.4 (4.8)</td>
</tr>
<tr>
<td>$V_E$ (L·min$^{-1}$)</td>
<td>52.6 (9.1)</td>
<td>64.9 (13.0)</td>
</tr>
<tr>
<td>$V_T$ (L)</td>
<td>2.5 (0.7)</td>
<td>2.9 (0.3)</td>
</tr>
<tr>
<td>BF (Breaths·min$^{-1}$)</td>
<td>23.2 (5.4)</td>
<td>24.6 (4.7)</td>
</tr>
<tr>
<td>HR (Beats·min$^{-1}$)</td>
<td>127.8 (13.7)</td>
<td>134.0 (11.3)</td>
</tr>
<tr>
<td>RPE</td>
<td>3.6 (1.1)</td>
<td>4.7 (1.2)</td>
</tr>
</tbody>
</table>

Values are mean (SD).

* a significant group main effect; b significant intensity main effect; ab significant group by intensity interaction; * significant difference between groups $p < 0.05$; * HR at 90% GET, STT n = 12, LTT n = 12. HR at Peak, STT n = 13, LTT n = 12.
GET: Gas exchange threshold; STT: Short-term trained; LTT: Long-term trained; VO₂: Oxygen utilization; V̇E: Minute ventilation; V̇T: Tidal volume; BF: Breathing frequency; HR: Heart rate; RPE: Rating of perceived exertion.

Table 3. Systemic oxygen utilization, ventilation, heart rate and rating of perceived exertion of short-term trained and long-term trained older men at 25%, 80% and 90% Gas Exchange Threshold during Square-Wave Constant Load (SWCL) cycling.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Test</th>
<th>Main effect for group</th>
<th>Group x intensity interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Df</td>
<td>F</td>
</tr>
<tr>
<td>VO₂ (mL·kg⁻¹·min⁻¹)</td>
<td>SWCL</td>
<td>1,25</td>
<td>37.851</td>
</tr>
<tr>
<td></td>
<td>RI</td>
<td>1,25</td>
<td>33.377</td>
</tr>
<tr>
<td>VO₂ (L·min⁻¹)</td>
<td>SWCL</td>
<td>1,25</td>
<td>5.091</td>
</tr>
<tr>
<td></td>
<td>RI</td>
<td>1,25</td>
<td>2.19</td>
</tr>
<tr>
<td>BF (Breaths·min⁻¹)</td>
<td>SWCL</td>
<td>1,25</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td>RI</td>
<td>1,25</td>
<td>0.051</td>
</tr>
<tr>
<td>HR (Beats·min⁻¹)</td>
<td>SWCL</td>
<td>1,25</td>
<td>1.179</td>
</tr>
<tr>
<td></td>
<td>RI</td>
<td>1,21</td>
<td>0.108</td>
</tr>
<tr>
<td>RPE (Beats·min⁻¹)</td>
<td>SWCL</td>
<td>1,20</td>
<td>0.491</td>
</tr>
<tr>
<td></td>
<td>RI</td>
<td>1,25</td>
<td>0.15</td>
</tr>
<tr>
<td>V̇L ΔHHb</td>
<td>SWCL</td>
<td>1,24</td>
<td>0.932</td>
</tr>
<tr>
<td></td>
<td>RI</td>
<td>1,22</td>
<td>3.213</td>
</tr>
<tr>
<td>V̇GAST ΔHHb</td>
<td>SWCL</td>
<td>1,23</td>
<td>7.537</td>
</tr>
<tr>
<td></td>
<td>RI</td>
<td>1,25</td>
<td>0.001</td>
</tr>
<tr>
<td>V̇PFC ΔHHb</td>
<td>SWCL</td>
<td>1,25</td>
<td>7.599</td>
</tr>
</tbody>
</table>

RI: Ramp incremental; SWCL: Square-wave constant load; VO₂: Systemic oxygen utilization; V̇E: Minute ventilation; V̇T: Tidal volume; BF: Breathing frequency; HR: Heart rate; RPE: Rating of perceived exertion; VL: Vastus lateralis; GAST: Gastrocnemius; PFC: Pre-frontal cortex; HHb: deoxyhemoglobin. * Significant p < 0.05.
Figure 1. Mean ΔHHb in the *vastus lateralis*, *gastrocnemius* and pre-frontal cortex within Ramp Incremental cycling. Panel (A) ΔHHb in the VL. Panel (B) ΔHHb in the GAST. Panel (C) ΔHHb in the PFC. STT 0 - 8 min (n = 14); 8 - 11 min (n = 9 - 13); 11 - 13.5 min (n = 2 - 8). LTT 0 - 10.5 min (n = 14); 10.5 - 13 (n = 8 - 13); 13 - 15.5 (n = 2 - 8). Square trace LTT, diamond trace STT.

Figure 2. Mean ΔHHb in the *vastus lateralis*, *gastrocnemius* and pre-frontal cortex during Square-Wave Constant load cycling. Panel (A) ΔHHb in the VL. Panel (B) ΔHHb in the GAST. Panel (C) ΔHHb in the PFC. Square trace LTT, diamond trace STT.
Figure 3. Group mean ΔHHb in the VL, GAST and PFC during Ramp Incremental cycling. Panel (A) ΔHHb in the VL. Panel (B) ΔHHb in the GAST. Panel (C) ΔHHb in the PFC at 90% of GET and peak exercise. Pattern fill STT, solid fill LTT. * Significant (p < 0.05) differences between groups.

Figure 4. Group mean ΔHHb in the VL, GAST and PFC during Square-Wave Constant Load cycling. Panel (A) ΔHHb in the VL. Panel (B) ΔHHb in the GAST. Panel (C) ΔHHb in the PFC at 25%, 80% and 90% of GET. Pattern fill STT, solid fill LTT. * Significant (p < 0.05) differences between groups.
DISCUSSION

This study examined systemic \( \dot{V}O_2 \), and \( O_2 \) extraction (\( \Delta HHb \)) in the VL, GAST and PFC at peak and sub- GET intensities between short-term and long-term aerobically trained men aged 40 - 60 yr, who were matched for current training load. The primary findings were that \( \dot{V}O_2 \) was significantly higher in LTT compared to STT, and \( O_2 \) extraction (\( \Delta HHb \)) was greater in GAST but not the VL or PFC in LTT compared to STT. These data suggest that without decreasing training volume per year, additional years of training can significantly improve \( \dot{V}O_2 \)peak for which increased muscle \( O_2 \) extraction may be a major contributing factor. While this result supports the suggestion that peripheral adaptations are likely to be responsible for increases in \( \dot{V}O_2 \)peak from aerobic training (33), as peak cardiac output was not measured in the present study it is not possible to quantify the effect the greater \( O_2 \) extraction had on the higher \( \dot{V}O_2 \)peak in LTT.

The \( \dot{V}O_2 \)peak values in the LTT (2.6 ± 0.4 L.min\(^{-1} \) / 39.4 ± 5.8) and STT (2.1 ± 0.4 L.min\(^{-1} \) / 51.7 ± 6.1) are consistent with normative values of well-trained men aged 40 - 60 yr (50). These data support the hypothesis in that the additional training years of the LTT resulted in significantly higher \( \dot{V}O_2 \)peak than the STT. The present results support the findings of a similar study of women aged 40 - 60 yr (8), and results of a longitudinal study; where over a 10-year period starting from the age of 42 - 45 yr, men who were already somewhat trained increased their \( \dot{V}O_2 \)peak without changing their training volume (29). Collectively, these studies suggest that while gains in \( \dot{V}O_2 \)peak significantly plateau within ~ 24 months of starting aerobic exercise training (27, 46), with regular training and maintained training volume, \( \dot{V}O_2 \)peak can continue to increase for 5 - 10 yr between the ages of 40 - 60 yr.

In the present study, \( \dot{V}O_2 \) at GET was, as expected, significantly higher in LLT compared to the STT. However, an unexpected finding was that this difference still existed when expressed as a percentage of \( \dot{V}O_2 \)peak. This result suggests a higher GET as a percentage of \( \dot{V}O_2 \)peak may be associated with higher \( \dot{V}O_2 \)peak. While previous studies support the possible influence of GET on \( \dot{V}O_2 \)peak and performance, \( \dot{V}O_2 \)peak, not GET is regarded as the major determinant of aerobic exercise performance in adults.

For \( \dot{V}O_2 \) during SWCL, the present results supported our hypothesis in that \( \dot{V}O_2 \) was significantly higher in LTT compared to STT while cycling at a power calculated to be 25\%, 80\% and 90\% of GET. Furthermore, the difference between groups increased with increases in intensity (as indicated by the ANCOVA interactions) from 0.2 L \cdot min\(^{-1} \) at 25\%, to 0.4 L \cdot min\(^{-1} \) at 80\% and 0.5 L \cdot min\(^{-1} \) at 90\% of GET. Similar results have been reported as a function of aerobic training in older men (21) and women (8, 13). Taken together these data suggest that aerobic exercise increases systemic \( O_2 \) utilization during sub- GET constant load exercise.

Differences in pulmonary ventilation (\( V_E \), \( V_T \), BF) have been previously reported between STT and LTT older women (8). Concurring with the findings of that study, there was a significant interaction for \( V_E \) in SWCL in the present study. However, there were no significant differences between groups for \( V_T \) and BF in either the RI or SWCL in the present study. This provides
further support for the suggestion that the effects of aerobic exercise on ventilation may be different between sexes (1, 8).

For ΔHHb in the VL during RI, the present data were contrary to the hypothesis with ΔHHb not being different between STT and LTT. However, in support of the hypothesis ΔHHb in the VL was not different between groups during SWCL. This finding suggests that in men aged 40 - 60 yr, additional training years beyond 24 months may not improve O₂ extraction (ΔHHb) in the VL at any intensity.

Previously, only two studies have investigated the effect of aerobic exercise training on muscle tissue O₂ extraction (ΔHHb) in exercising adults between 40 and 60 yr (8, 21). Within the first study (21) the matching of O₂ distribution (VO₂) and extraction (ΔHHb) in the VL was compared in untrained and long-term (≥ 7 yr) trained men aged 40 - 59 yr during transitions from light to moderate exercise below GET. The faster VO₂ but not ΔHHb kinetics (thus a lower ΔHHb: VO₂ ratio) in the trained compared to the untrained indicated a better matching of local O₂ delivery to extraction. Furthermore, while peak exercise tests were conducted in the previous study to calculate the work load (as a percentage of GET) for subsequent sub- GET tests, no peak ΔHHb values were presented. The results of the second study (8) on short and long-term trained women aged 40 - 60 yr do not support those of the present study with the LTT compared to the STT having greater peak ΔHHb in the RI, and at the same relative intensity during the SWCL test (8). Collectively, these results suggest that sex differences exist in the relative contribution that peripheral and central components have on increases in, or maintenance of VO₂peak in adults aged 40 - 60 yr.

For the ΔHHb in the GAST, the present results were contrary to the hypothesis with the ΔHHb in the GAST significantly greater in LTT compared to STT during SWCL but not during RI. This new finding suggests that in men aged 40 - 60 years, long-term (> 5 years) aerobic exercise provides adaptations to and/or maintains the ability of the GAST muscle to utilize O₂ during sub- GET exercise, which was not observed in the VL. Previously, only three studies have reported oxygenation (HHb or O₂Hb) changes in the GAST during exercise (8, 25, 31), with only one of these investigating the effect of aerobic training (8). In that study on STT and LTT women (40 - 60 yr), the ΔHHb in the GAST was not significantly different between groups during RI and SWCL exercise (8). Possible explanations for the disparity in the results between these two studies include sex difference in muscle fiber distribution (28), and reduced leg blood flow and perfusion pressure reported in older women (43). However, the opposing HHb patterns of the GAST (which decreased substantially) and the VL (which progressively increased) at the onset of exercise in the present study were also observed in women (8). This could potentially be due to a greater increase in mechanical vasoconstriction at the GAST compared to the VL at the onset of cycling, with the initial increase in blood flow during exercise (in the lower limbs) being driven by muscle pump activation (54).

Compared to the GAST, the VL has a low percentage of Type I fibers and a higher percentage of Type IIa and IIx fibers that contribute to a faster onset of O₂ extraction (14, 24). Furthermore, age-related reductions in citrate synthase activity and thus oxidative capacity have been
reported in the GAST but not VL in older men, with VO_{2peak} positively related to citrate synthase in the GAST but not the VL (26). The higher O_{2} extraction (ΔHHb) in the GAST but not the VL in LTT compared to STT in the present study suggests that long-term (> 24 months) aerobic exercise might reduce the age-related reductions in citrate synthase activity and muscle oxidative capacity in the male GAST.

For the ΔHHb in the PFC during RI, the present results support the hypothesis in that the ΔHHb was not different between STT and LTT at 90% of GET or at peak exercise. However, an unexpected finding was the greater ΔHHb in the PFC in LTT compared to STT at 90% of GET during SWCL exercise. This finding suggests that the additional training years of the LTT may not affect O_{2} extraction in the PFC at peak exercise. However, during moderate intensity constant load exercise for a longer duration (20 min), the present data suggest LTT older men utilize more O_{2} in the PFC compared to STT older men.

In attempting to link PFC oxygenation and fatigue, there are multiple studies and reviews on oxygenation patterns in the PFC during exhaustive exercise (4, 45, 52), and following aerobic training in men (42, 48). Despite this, there are currently no data on sub-maximal constant load exercise, thus the present findings are unique. It is plausible that the greater ΔHHb in the PFC in LTT compared to STT at 90% of GET is related to the higher VO_{2peak} in the LTT. However, in contrast, a systematic review reported that a positive relationship exists between ΔHHb in the PFC and VO_{2peak} at hard to very hard intensity exercise but not at light to moderate exercise (45). Furthermore, changes in cerebral blood flow, partial pressure of arterial carbon dioxide and cerebral autoregulation at different intensities during exercise may explain the variations in ΔHHb in the PFC between LTT and STT in the present study (39).

A potential limitation of this present study was that while regular cycling was a requirement for recruitment, cycling was not necessarily each participants’ major mode of aerobic exercise and the amount of cycling completed by the participants in each group may have changed during the respective training (years). This could have influenced the cycling technique, and thus muscle activation. Another potential limitation is that the ramp data was not left shifted to account for the mean response time of VO_{2}, thus potentially overestimating the power output at GET. Furthermore, while differences were found between groups it is acknowledged that these were within a cross sectional design.

The results of this study have implications for aerobic exercise in men aged 40 - 60 yr. Specifically, the present data suggest that, in addition to the typical adaptive improvements in systemic O_{2} utilization, and peripheral O_{2} extraction following starting of regular aerobic exercise, additional years of training without necessarily increasing training volume, may provide significant further improvements. Future research could include training studies extending beyond 12 months and monitor changes in central delivery to, and the extraction of O_{2} in multiple peripheral tissues.

It is concluded that in men aged 40 - 60 yr, regular aerobic exercise beyond 24 months significantly increases VO_{2} at peak and sub- GET exercise intensities, without increased current
training volume. Concomitant with these adaptations there is increased O$_2$ extraction ($\Delta$HHb) in the GAST and PFC at moderate intensity (sub- GET) exercise, but not at peak exercise.

ACKNOWLEDGEMENTS

Hugo Kerhervé and Yuri Kriel provided technical assistance.

REFERENCES


40. Okushima D, Poole DC, Barstow TJ, Rossiter HB, Kondo N, Bowen TS, Amano T, Koga S. Greater VO2peak is correlated with greater skeletal muscle deoxygenation amplitude and hemoglobin concentration within individual muscles during ramp-incremental cycle exercise. Physiological Reports 4(23): 2016.


