Voluntary Hypoventilation at Low Lung Volume (VHL) During Strength and Conditioning Training Increases Anaerobic Performance: A Pilot Study

Zachary Hundley †*
†Liberty University, Lynchburg, VA
*United States Air Force, Hurlburt Field, FL

In preparation for Master’s thesis defense.
Voluntary Hypoventilation at Low Lung Volume (VHL) During Strength and Conditioning Training Increases Anaerobic Performance: A Pilot Study

Zachary Hundley †*
†Liberty University, Lynchburg, VA
*United States Air Force, Hurlburt Field, FL

In preparation for Master’s thesis defense.

APPROVED BY:
Dr. Jared H. Hornsby, Ph.D., CSCS, Committee Chair
ABSTRACT
To determine whether a VHL protocol implemented into an already existing strength and conditioning program could improve anaerobic conditioning more efficiently within the military population. Six active duty males completed a seven-week training cycle with VHL protocols implemented on each training day (2-4 days/week). Before (Pre) and after (Post) protocol implementation, the participants performed a multi-stage 20-m shuttle run test (MSRT). After incorporating VHL, participants significantly improved their MRST scores by an average of 50.3%. Additionally, Body Oxygen Level Test (BOLT) scores were improved across the duration of the study. This study showed employing VHL can improve anaerobic performance in the MSRT within the military population. Given the need for training efficiency, utilizing VHL could provide a safe and cost-effective training stimulus to improve anaerobic performance.
KEY WORDS: Breath-hold, Hypoventilation, Military, Hypoxic-training, MSRT

INTRODUCTION
When compared to other essential physiological processes in the body, respiration is unique in that it is primarily an autonomic process but can also be intentionally controlled. Humans have been consciously manipulating the breath since antiquity, predominately to forage the seafloor or to explore higher altitudes (Bailey, 2004). Although such activities alter the automatic breathing pattern, it is done in response to an external factor (i.e., subsurface diving or reduced oxygen at higher altitudes). Even with a long history of respiratory manipulation, it was not until more recent times that humans began to simulate external factors by intentionally reducing breathing frequency (hypoventilation) by introducing voluntary breath holds (Woorons, 2014a).

Long-distance running legend Emil Zatopsk (Olympic gold medalist 1948 & 1952) was one of the first athletes in modern time who used breath holds during training. Zatopsk would routinely hold his breath for a given number of strides (Tjelta & Enoksen, 2001). Almost two decades later, after noting the drop in performance during the Mexico City Olympics in 1968 (altitude 7,200 ft), world-renowned swimming coach James Counsilman speculated that his athletes could mimic high altitude conditions by decreasing the breathing rate. In theory, this would decrease the amount of oxygen (O2) and increase lactic acid (La) concentration in the muscles, eliciting an adaptation response (Counsilman, 1975).

Soon the first studies investigating “hypoxic training” were published and concluded that hypoventilation during exercise did not significantly lower O2 concentrations or increase lactic acid concentrations, but did increase CO2 concentrations (Holmer & Gullstrand, 1980; Hsieh & Hermiston, 1983). However, several years later, it was noted that combining hypoventilation with breath holds at low lung volume, significantly decreased arterial O2 saturation (Woorons et al., 2006 & Woorons et al., 2008). Further investigations supported initial studies and demonstrated that arterial O2 saturation similar to that of altitude training could be achieved (Millet et al., 2010; Woorons et al., 2014).

The primary mechanisms associated with voluntary hypoventilation at low lung volume (VHL) are complex and affect the respiratory, circulatory, and musculoskeletal systems. On a systemic level, VHL produces hypercapnia and hypoxia, which induces both acute metabolic and respiratory acidosis. Putting the body under such a stimulus has improved anaerobic capacity in
both open- (Trincat, Woorons, & Millet, 2017; Fornasier-Santos, Millet, & Woorons, 2018) and closed-loop testing (Woorons, Millet, & Mucci, 2019).

The military population provides a unique demographic that stands to benefit greatly from reported VHL training. In addition to primary duties, service members are expected to maintain a competent level of physical fitness throughout a broad range of capacities. Thus, physical training regimens need to be efficient, yet cover a comprehensive range of physical demands. Adversely, it is well documented that overuse injuries caused by mono-structural training are one of the most prevalent and detrimental sources of lost man-hours and money throughout the military (Kaufman, Brodine, & Shaffer, 2000; Roy, 2011; Schwartz et al., 2018).

The current study implemented VHL protocols during strength and conditioning training sessions in a military population. By implementing VHL protocol to already existing strength and conditioning programs, military personnel could potentially improve anaerobic conditioning more efficiently, cutting down on total training time, thus reducing the likelihood of overuse injuries.

METHODS

COVD-19 Note
The initial study design was altered to ensure maximal safety and minimize risk to those involved. Weekly training was administered in a small group setting, following social distancing guidelines layout by the United States Air Force (Appendix A). Similarly, when researchers met with participants, researchers wore masks and followed social distancing guidelines outlined by the location where the meeting took place. All training and testing were completed outdoors when possible. Additionally, base-wide sanitation and sterilization protocols for all gyms and training locations were in place.

Participants
This study was approved by the Liberty University Institutional Review Board (IRB #: IRB-FY19-20-402) and the Human Performance Program (HPP) of Duke Airfield, Florida. Participants originally recruited consisted of active-duty military members (n=16, 15 males, 1 female), ages 32-43, currently following a strength and conditioning training program provided by the HPP strength and conditioning staff during their off-duty physical training regiment. Recruiting occurred in-person before the implementation of the study. Interested volunteers were briefed on the basics of the study and had a chance to ask questions. After the brief, if participants choose to volunteer for the study, consent and medical history forms were completed and signed.

Experimental Design
Initial Testing (Week 0): At the beginning of Week 0, participants completed an initial battery of biometric measurements and assessments to obtain a baseline. Participants completed an InBody (InBody 570, InBody USA, Cerritos, California, USA) scan to obtain their height, weight, body fat, and lean body mass. Soon thereafter, participants completed their standard warm-up (per the HPP), followed by the multi-stage 20-m shuttle run test (MSRT) (Leger et al., 1988; Canino et al., 2018).

Education/Familiarization (Week 0): Within 5 days of initial testing, participants were educated on the basic breathing physiology and how voluntarily changing breathing patterns can affect
physiology. The protocols used in the current study were introduced and participants were able to practice and ask questions as needed until they felt confident in executing the protocol on their own.

Implementation (Week 1-7): The breathing protocol implemented during this study was divided into three main portions. At the beginning of each training session, participants completed the first portion known as a Body Oxygen Level Test (BOLT) (Stanley et al., 1975) by taking three deep breaths, followed by a breath-hold after the exhale of the third breath. Participants timed the length of the breath-hold and reported their results.

The second portion of the protocol coincided with the mono-structural warm-up (per the HPP), in which nasal breathing and breath-holds were utilized during a given movement (Rogue Echo Bike, Rogue Fitness, Columbus, OH, USA; Concept2 Rower, Concept2 Inc., Morrisville, VT, USA, etc.) performed at an easy to moderate intensity. Breath-holds were taken after the exhale and held until participants begin to feel the initial desire to breathe (taught during education/familiarization brief). Breath-holds were repeated every two breaths for the duration of the five minutes warm-up. This cyclic, exhale-hold breathing pattern was the primary breathing pattern used for the second and third portions of the protocol.

The last portion of the protocol occurred twice a week during the conditioning segment of the program. Participants performed a given exercise for 30-120 seconds in order to obtain a moderate to high heart rate. Immediately after, participants performed a variation of a weighted carry (utilizing kettlebells or dumbbells) or static hold (depending on the session) for a prescribed duration. During the carry/static hold, participants would utilize the cyclic, exhale-hold breathing pattern in which breath-holds would be taken after every second or third breath. Specific training example session can be seen in Appendix B.

Post-Study Testing (Week 8): After 7 weeks of following the breathing protocol, participants completed the same physiological measurements and assessments as initial testing. All data was then complied and statistically analyzed.

Statistics
Due to this research study being a pilot study, only descriptive statistics (means and standard deviations) were calculated.

RESULTS
Of the sixteen original participants that began the study, six males were able to complete the seven-week program. Pre- and post- anthropometrics and performance metrics are illustrated in Table 1. Weekly BOLT scores were plotted in Figure 1. with values listed in Table 2.
Table 1: Pre- and Post- Anthropometrics and Performance Metrics

<table>
<thead>
<tr>
<th>Metric</th>
<th>Mean ± SD</th>
<th>Pre</th>
<th>Post</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSRT (Stage)</td>
<td>43.3 ± 9.4</td>
<td>64.5 ± 12.9*</td>
<td></td>
</tr>
<tr>
<td>Body Weight (kgs)</td>
<td>91.9 ± 7.3</td>
<td>91.8 ± 7.8</td>
<td></td>
</tr>
<tr>
<td>Body Fat (%)</td>
<td>19.9 ± 3.5</td>
<td>20.6 ± 2.1</td>
<td></td>
</tr>
<tr>
<td>Muscle Mass (kgs)</td>
<td>42.5 ± 4.1</td>
<td>41.9 ± 3.9</td>
<td></td>
</tr>
</tbody>
</table>

* Statistically Significant

Figure 1: Weekly BOLT Scores
Table 2: Mean Difference of BOLT Scores

<table>
<thead>
<tr>
<th>ID #</th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
<th>Week 7</th>
<th>Mean Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>#8</td>
<td>27</td>
<td>25</td>
<td>20*</td>
<td>23</td>
<td>20</td>
<td>26</td>
<td>32#</td>
<td>12</td>
</tr>
<tr>
<td>#13</td>
<td>17</td>
<td>15*</td>
<td>16</td>
<td>20</td>
<td>21</td>
<td>20</td>
<td>24#</td>
<td>9</td>
</tr>
<tr>
<td>#5</td>
<td>23</td>
<td>25</td>
<td>27</td>
<td>22*</td>
<td>32</td>
<td>35#</td>
<td>32</td>
<td>10</td>
</tr>
<tr>
<td>#3</td>
<td>NA</td>
<td>20*</td>
<td>21</td>
<td>NA</td>
<td>23</td>
<td>NA</td>
<td>27#</td>
<td>7</td>
</tr>
<tr>
<td>#11</td>
<td>22</td>
<td>20</td>
<td>20*</td>
<td>27</td>
<td>21</td>
<td>25</td>
<td>32#</td>
<td>12</td>
</tr>
<tr>
<td>#7</td>
<td>21*</td>
<td>25</td>
<td>30#</td>
<td>NA</td>
<td>NA</td>
<td>25</td>
<td>24</td>
<td>9</td>
</tr>
</tbody>
</table>

* Member’s lowest BOLT score
# Member’s highest BOLT score

DISCUSSION
This study investigated the relationship between VHL and its effects on anaerobic conditioning. After incorporating VHL into a standard strength and conditioning program for seven weeks, participants significantly improved their MRST scores by an average of 50.3%. Additionally, BOLT scores were improved across the duration of the study. Although anaerobic performance was indirectly measured, the results suggest that utilizing VHL during training will improve anaerobic capacity.

Previous studies have drawn similar conclusions when VHL was applied. Trincat, Woorons, & Millet (2017) utilized VHL training to improve swim-sprint ability by 35% after only six sessions compared to the same sprint training completed with normal breathing. Fornasier-Santos, Millet, & Woorons (2018) noted similar results in rugby players who implemented VHL for eight sessions of sprint training. Athletes that used VHL during training sessions improved repeat-sprint ability (RSA) by 64% (p < 0.01) versus athletes that completed the same training while breathing normally (6%; p = .74). Additionally, Woorons, Millet, & Mucci, (2019) also reported improvements in maximal power output (7.7%; p < 0.01) and VO2 during six second sprints (26.3%; p < 0.01) when participants completed six cycle ergometer training sessions utilizing VHL.

The current study, like those previously mentioned, convey the benefit of implementing VHL protocols. In regards to the underlying physiological mechanism, there are varying potential explanations that are currently being researched. One broad perspective is that VHL could induce oxygen saturation and other physiological responses similar to training at high-altitude (Woorons et al., 2008; Woorons et al., 2014b). However, on cellular level, data suggests that the hypoxic dose achieved during VHL training does not yield the same cellular changes seen in constant hypoxic conditions Woorons, Millet, & Mucci, (2019).

Additionally, earlier studies (Woorons et al., 2010; Trincat, Woorons, & Millet, 2017) attributed the benefits of VHL training to improvements in the anaerobic glycolysis pathway caused by adaptations to an increase in blood lactate concentrations. However, Woorons, Millet, & Mucci, (2019) noted that increases in blood lactate concentrations are not consistent across the literature and suggest that the duration and/or intensity level of exercise may explain these differences.
Woorons, Millet, & Mucci, (2019) also noted that additional adaptations could be taking place that would increase one’s ability to buffer acidic by-products of anaerobic glycolysis.

Furthermore, Woorons, Billaut, & Vandewalle (2020) also noted that a higher VO$_2$ could be attributed to the pump effect that is caused by the augmented stroke volume coinciding with rhythmic breath-holds. More recently, Lapointe et al. (2020) noted an increased total electrical activity and power spectrum frequency. The authors of the study attributed this finding to enhanced re-oxygenation during recovery phases, but also mentioned that increased CO$_2$ could affect cerebral blood flow which could affect central motor command.

Ultimately, there are many variables at play making for an extremely complex cause-and-effect reality. The study of VHL is still in its infancy, but that shouldn’t detract from the fact that given the simplicity and safety of implementing VHL into current training strategies, VHL could offer coaches and athletes another modality to improve anaerobic performance. That said, the limitations of the current study should be noted since there was a small sample size of only males, all with a similar athletic background. Additionally, due to the sporadic nature of their careers, utilization of VHL was not perfectly consistent over the seven-week period. Future research should be considered to broader demographics, increasing biomarkers tracked, and implementing multiple VHL protocols as needed.

In conclusion, VHL improved anaerobic performance in the MSRT within the military population. While the underlying mechanisms of the physiological responses are still unknown. The current findings suggest that VHL can improve performance in an already trained population. Given the need for training efficiency, utilizing VHL could provide a safe and cost-effective training stimulus to improve anaerobic performance.

**Practical Application**
In terms of application, the results of this study suggest that utilizing a cyclic breathing pattern during strength and conditioning training can improve anaerobic performance. Implementing cyclic breathing patterns that employs breath-holds after the exhale can be used throughout warm-ups and low-coordination movements. However, it is important to remember that when conducting any type of breath holding, there is always the chance of dizziness and loss of coordination. Therefore, it is important that strength and conditioning professionals pair breathing protocols with movements that athletes can perform with little to no risk for injury. Specific VHL training circuits used in this study are listed in Appendix B.
REFERENCES


MEMORANDUM FOR ALL MAJCOM/DCOMs

FROM: HQ USAF/A4
1030 Air Force Pentagon
Washington, DC 20330-1260

SUBJECT: COVID-19 Response – Adapting Workspaces to Promote Physical Distancing

Reference: (a) AFMISC memorandum, “Guidance for implementing precautionary measures and increasing custodial services as a result of Coronavirus COVID-19,” 17 Mar 2020

As we continue to operate in this new environment, the Department of the Air Force must adapt to the disruptions of installation workspaces, programs, services, and processes using a combination of administrative policies and minor facility enhancements.

Commanders should implement telework optimization and administrative policies first before making significant or permanent alterations to existing workspaces. These efforts will help achieve the desired effect of reducing potential exposures and prevent the creation of workplace modifications that could introduce inefficiencies.

Appendix A outlines considerations Commanders could implement in order to adapt workspaces to promote physical distancing. Any requirement executed in line with this guidance shall be ESP coded C1 as a COVID-related cost.

Please refer any questions to HQ USAF/A4CPS, Lt Col Matthew Anderson, DSN 223-9519, or by e-mail at matthew.k.anderson8.mil@mail.mil.

Attachments
Appendix A: Facility Considerations for Reducing Potential Exposures
Appendix A

Facility Considerations for Reducing Potential Exposures

This guidance is intended to provide Installation Commanders facility space and utilization modification recommendations to promote physical distancing when developing “return to the workplace” plans. Commanders should implement telework optimization and administrative policies first before making significant or permanent alterations to existing workspaces. These efforts will help achieve the desired effect of reducing potential exposures and prevent the creation of workplace modifications that could introduce inefficiencies.

1. Administrative Policies to Reduce Potential Exposures

Administrative policies should be the primary method used to reduce potential exposure when developing “return to the workplace” plans.

Employees should self-assess their health before leaving home. If experiencing a temperature, or not feeling well, employees should remain at home and not enter the workplace.

All personnel shall wear cloth face coverings inside buildings where physical distancing cannot be maintained, based on current CDC and local guidance and advisories.

All personnel shall wash their hands or utilize hand sanitizer frequently throughout the work day, per CDC guidelines.

Commanders and supervisors should continue to maximize the use of virtual meetings.

1.1 Cleaning Standards

Increased workspace cleaning standards will be an integral part of a “return to the workplace” plan. Commanders should consider the following:

- Consult with HQ AFIMSC guidance and CDC guidelines to increase the cleaning of common and high-traffic areas

- Install self-cleaning sanitation stations (wipes and/or hand sanitizer) to support increased cleaning of personal workspaces and common areas, per CDC guidelines

- Implement requirements for Airmen to be responsible for their own spaces such as wiping down frequently touched surfaces in the immediate work area

- Wipe down door handles/fixtures frequently
1.2 Telework Optimization

Leverage teleworking protocols. Any potential funds spent to reconfigure a workplace should first be measured against investing in a strengthened VPN back-bone and suite of on-line collaboration tools. Additionally, Commanders should consider adding web-based conferencing capabilities to meeting rooms that are compatible with programs (such as Microsoft Teams) to maximize the ability to collaborate between in-office workers and teleworkers.

1.3 Administrative Work Areas

To the extent practicable, reconfigure administrative space furniture to promote physical distancing.

- As appropriate, adjust workforce time and attendance; take into consideration other factors such as Blue/Silver shifts, continued telework, ability to ‘distance’, etc.

- Reconfigure waiting areas by reducing seating capacity to accomplish physical distancing

- Encourage virtual / online customer services

- Encourage the use of surface materials that are easier to sanitize.

- Encourage reducing or modifying the equipment needed at each shared workstation to eliminate shared materials.

- Encourage use of virtual collaboration tools instead of in person meetings

- Reduce the number of students in instructor-led classroom courses

- Enable on-line appointments in advance for services that require in-person customer interaction

1.4 Industrial Work Areas

A telework solution may not be as applicable for industrial workspaces. Consideration to reduce potential exposure in an industrial area should include:

- Reduce personnel density in industrial areas through workforce time and attendance; take into consideration other factors such as Blue/Silver shifts, ability to ‘distance’, etc.

- Encourage aggressive use of PPE

- Utilize additional handwashing/sanitizing stations in the shop spaces
2. Facility Enhancements

To the extent practicable, facility enhancements aimed to physically eliminate hazards should be paired with administrative policies to promote physical distancing. This can be done through user purchased and installed equipment items or Real Property Installed Equipment (RPIE). Time and cost intensive facility modifications should be avoided. Focus RPIE investment in high traffic and/or high density locations. Some low cost, easy to execute, potentially reversible actions to consider are:

- Equipment Purchases
  a. Adding temporary plastic sheeting or Plexiglas dividers between critical high density workspaces
  b. Place floor markings as guides for physical distancing in areas where employees may congregate, such as common printers and copiers; refrigerators, etc.
  c. Purchase portable HEPA/UV filtration units for high-risk areas

- RPIE
  a. Install touchless fixtures (kick plates, sensors, door openers, water fountains, paper towel dispensers, soap dispensers, etc.)
  b. Install the highest Minimum Efficiency Reporting Value rated HVAC filter available based on the system design
  c. Consult SMEs on potentially increasing outside-air configurations on HVAC systems
Appendix B

General Training Blueprint

- Elevate heartrate via exercise for :30-1:20 seconds. Target different heart rate zone or intensities throughout a given week of training.
- Right after primary exercise, perform a low-coordination movement while implementing VHL cyclic breathing. For this study, weighted carries and static isometrics were utilized.
- Recover for a given amount of time then repeat for 4-8 rounds.

Training Example #1: Fan Bike/Row + KB Front Rack Carry
8 Rounds:
1) :30 secs max effort on fan bike (Substitute Rower, SkiErg, etc. if needed)
2) Dismount equipment and take three deep breaths in through the nose, out through the mouth.
3) On the third exhale, go into a breath hold and clean two KBs (or DBs) into the front rack position.
4) Begin walking as far as possible before you have a strong urge to breath.
5) Stop with the kettlebells in the front rack while you perform your two cyclic breaths then go into another carry during your next breath hold. Perform a total of five breath holds per round.
6) Recover for 2:00 minutes and go into the next round.

Training Example #2: Cals + Wall Sits
5 Rounds:
1) Perform :30 seconds of each of the following calisthenics as fast as possible - jumping lunges, pushups, mountain climbers, and air squats for a total time of 2 minutes of work.
2) After the 2 minutes of work, take three recovery breaths - in through the nose, out of the mouth.
3) Place your back against a wall and sit down into a 90-degree wall sit. Take a breath and after the exhale go into a breath hold.
4) Once you have a strong urge to breath, take two recovery breaths. After the second exhale, go into a hold again. Repeat until you have completed five breath holds (always after the exhale).
5) After your fifth hold, recover for 60-90 seconds and go straight into the next round. If you find yourself able to breath in and out of your nose prior to the 60 seconds, challenge yourself to begin the next round early.

Training Sessions #6: Upper Body Volume + Isometric Hold
4x3 Rounds:
1) Pick four exercises that target your weakest upper body muscle groups. Banded exercises are recommended (ex. banded push downs, face pulls, curls, pull-aparts, rows, etc.)
2) Perform :45 seconds of a given exercise, followed immediately by :45 seconds of an mid-range isometric hold, during which you will utilize a two breath + exhale hold sequence.
3) After the :45 seconds of the isometric hold, recover for :30 seconds. This equals one round. Finish all three rounds for a given exercise before moving onto the next exercise.