Further Test and Evaluation of the Aqua-Lung Portable Helicopter Oxygen Delivery System (PHODS) in the Altitude Chamber

Leonard Temme, Bobby Bowers, Amanda Hayes, Paul St. Onge, Aaron McAtee, Frank Petrassi, & Dennis Ard

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Further Test and Evaluation of the Aqua-Lung Portable Helicopter Oxygen Delivery System (PHODS) in the Altitude Chamber

Temme, L.¹, Bowers, B., Hayes, A., St. Onge, P., McAtee, A., Petrassi, F., & Ard, D.

Introduction: The Portable Helicopter Oxygen Delivery System (PHODS) is a hypoxia countermeasure that provides supplemental oxygen ($O_2$) to Army aviators in unpressurized aircraft at altitudes up to 18,000 feet (ft) above mean sea level (MSL). The present document is the presentation provided to the Aerospace Medical Association’s Annual Scientific Meeting (Reno, NV, May 2022) describing USAARL’s test and evaluation (T&E) of the PHODS conducted in the altitude chamber.

Methods: The PHODS T&E monitored: (1) peripheral blood $O_2$ saturation ($SpO_2$) using standard pulse oximetry, (2) regional cerebral blood $O_2$ saturation ($rSO_2$) using infrared spectroscopy, and (3) the Psychomotor Vigilance Task (PVT) performance, a tedious, intentionally boring visual monitoring task that reports visual reaction time as well as errors due to missed targets and false anticipatory responses. These measures were recorded at pressure altitudes (PA) of 14,000 and 17,800 ft above MSL as well as at ground level (GL). At each altitude, Army aircrew ($N = 22$) tested PHODS functionality and effectiveness during 10 minutes (min) of the PVT, 5 min. of verbalized text reading (TR), and 2 min of a physical workload (WL) task; i.e., self-paced squats.

Subject Terms
Portable Helicopter Oxygen Delivery System, PHODS, hypoxia, supplemental oxygen

Security Classification: UNCLASSIFIED

Limitation of Abstract
SAR

Number of Pages
30

Name of Responsible Person
Loraine St. Onge, PhD

Telephone Number
334-255-6906
In addition to mean and standard deviations on the rSO$_2$ and SpO$_2$, linear regressions calculated rSO$_2$ and SpO$_2$ slope over the testing periods of 10 min of PVT, 5 min TR, and 2 min WL.

Results: With PHODS, average SpO$_2$ fell by about 6% and rSO$_2$ by about 5 units at both 14,000 and 17,800 ft PA relative to GL, a statistically significant difference.

1. This relatively modest drop in SpO$_2$ and rSO$_2$ occasioned a delay of about 33 milliseconds in PVT reaction times relative to reaction time seen at GL; i.e., a delay of about 10% in the simplest response of the visual system to the sudden unpredictable onset of a light.

2. Data suggest a cumulative PVT fatigue or tedium at both 14,000 ft and 17,800 ft such that, on average, PVT response time during the last 5 minutes of PVT testing interval was statistically slower than response time recorded during first 5 minutes of PVT testing, an effect not seen at GL, possibly indicating a compound hypoxia and fatigue effect.

3. If these results indicate a slowing of neural processing through the central nervous system, the delays may be compounded and possibly disrupt normally synchronous signals and overt behaviors such as those supporting the ocular motor system as well as display refresh rates.

4. The SpO$_2$ data did not parallel the rSO$_2$ data in that rSO$_2$ fell over time during WL at 14,000 and 17,800 ft but SpO$_2$ did not fall.

5. The fall-off slope was related directly to altitude; the greater the altitude, the steeper the fall off.

6. Fall-off time course, severity, practical importance, and recovery rates remain to be assessed for WL durations longer than 2 minutes. Consequently, PHODS has shortcomings as a hypoxia countermeasure. We recommend enhancements for future Army aircraft particularly when aircrew workload is involved.
Further Test and Evaluation of the Aqua-Lung© Portable Helicopter Oxygen Delivery System (PHODS) in the Altitude Chamber

Leonard A. Temme, PhD¹, Bobby Bowers¹, Amanda Hayes¹, MS, Paul St. Onge, PhD¹, Aaron McAtee, MS¹,², LTC Frank Petrassi, PhD³, Dennis Ard³

¹U.S. Army Aeromedical Research Laboratory, Fort Rucker, AL
²Goldbelt Frontier, Alexandria, VA
³School of Army Aviation Medicine, Fort Rucker, AL

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Hypoxia remains one of the most important hazards in aviation, particularly for aircrew in non-pressurized aircraft at altitude.
Outline

1. Required oxygen use: Army Flight Regulation 95-1 a.(1) and a.(2)
2. Brief description of the PHODS
3. Description of PHODS test and evaluation methods
   a. Performance metric (Psychomotor Vigilance Test [PVT])
   b. Blood oxygen metrics
4. Results
   a. Performance metric (PVT)
   b. Blood oxygen metrics
5. Conclusions
“Approved oxygen systems will be used as follows:
“8-6: a. Unpressurized aircraft. Oxygen will be used by aircraft crews and occupants for flights as follows:

(1) Aircraft crews.
   (a) On flights above 10,000 feet pressure altitude (PA) for more than 1 hour.
   (b) On flights above 12,000 feet pressure altitude for more than 30 minutes.

(2) Aircraft crews and all other occupants.
   (a) On flights above 14,000 feet pressure altitude for any period of time
   (b) For flights above 18,000 feet pressure altitude, oxygen pre-breathing will be accomplished by aircrew members.”
PHODS

- Man-mounted
- Attached to survival vest and helmet
- Approved for use on
  - Chinook (CH-47)
  - Black Hawk (UH-60)
- Provides supplemental oxygen ($O_2$) at altitudes up to 18,000 feet (ft) above mean sea level (MSL)
- Question whether PHODS is still available
PHODS Components

- Flexible nasal cannula
- Quick disconnect hose assembly
- Inlet and outlet hoses
- Automatic oxygen pulse controller (OPC M1)
- Oxygen cylinder and regulator

Note: Crewmember mask not depicted
PHODS Oxygen Pulse Controller (OPC M1)

OPC M1 provides a predetermined amount of oxygen when it registers a pressure differential caused by the user’s breathing and its internal barometer that detects pressure altitude.

OPC M1 starts operation once it senses a pressure altitude of 8000 ± 500 ft.

OPC M1 controls pulse duration; the higher the altitude the longer the pulse.
Manufacturer’s Recommended Use of PHODS

<table>
<thead>
<tr>
<th>Flight Altitude</th>
<th>Delivery Method</th>
<th>PILOTS/LOW WORK LOAD</th>
<th>CE/EE/HEAVY WORK LOAD</th>
</tr>
</thead>
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<tr>
<td></td>
<td>OPC Mode</td>
<td>Nasal Cannula</td>
<td>Nasal Cannula</td>
</tr>
<tr>
<td>8K</td>
<td>ON</td>
<td>F20</td>
<td>F20</td>
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<tr>
<td>10K</td>
<td>ON</td>
<td>F20</td>
<td>F20</td>
</tr>
<tr>
<td>12K</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>14K</td>
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<tr>
<td>16K</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>18K</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
</tbody>
</table>

Note. PHODS nasal cannula or mask configuration depends altitude & workload.
Test and Evaluation of PHODS Efficacy

Independent variable: Altitude
- Ground level (GL), 14,000, 17,800 ft (School of Army Aviation Medicine [SAAM] Altitude Chamber)

Tasks / Challenges
- Psychomotor Vigilance Test (PVT) (10 minutes) – boring sedentary task
- Verbalized text reading (5 minutes) – speech challenge disrupting nasal breathing, decreasing cannula effectiveness
- Squats in place (2 minutes) – physical workload

Dependent variables
- Pulse oximetry (SpO₂) (continuous)
  - NONIN Life Sense Model LS1-9R
- Near Infrared Transcranial Spectroscopy (NIRS) (rSO₂) (continuous)
  - NONIN Equanox Model 7600
- PVT Performance (visual reaction time in milliseconds [ms])
School of Army Aviation Medicine Altitude Chamber

Altitudes tested
- Ground Level (PHODS inactive)
- 14,000 ft (PHODS active)
- 17,800 ft (PHODS active)

Personnel
- 4 Aircrew PHODS Testers (Total \( N = 22 \))
- 2 Test Coordinators
- 1 Chamber Observer
Altitude Chamber Flight Profile & Events

1. PVT
2. Text reading
3. Squats
4. Ear & sinus check
5. 30 minutes pre-breathing
SpO$_2$ during PVT

- **Ground Level**
- **14,000 ft**
- **17,800 ft**

Time (10 minutes)
rSO₂ during PVT

Ground Level

14,000 ft

17,800 ft

Time (10 minutes)
Mean SpO₂ & rSO₂ During PVT (10 minutes)

Mean SpO₂
Altitude ($F(2, 42) = 31.63, \ p < 0.01$)
SpO₂ GL > 14K & 17.8K, $p < 0.01$

Mean rSO₂
Altitude ($F(2, 42) = 43.47, \ p < 0.01$)
rSO₂ GL > 14K & 17.8K, $p < 0.01$
Psychomotor Vigilance Test (PVT)

PVT trial is 10 minutes of repeated visual reaction, recorded in milliseconds, to a stimulus onset occurring randomly between 2 to 10 second intervals.

On average, the database recorded 100 such reaction times (RT) for each trial.
Mean PVT Reaction Time (ms)

Mean PVT Reaction Time ± 1 SD
\(F(2, 40) = 19.7, \ p < 0.01\)
GL RT < 14K & 17.8K, \(p < 0.01\)
PVT with Mean SpO₂ & rSO₂

![Graph showing PVT with Mean SpO₂ & rSO₂](image-url)
Does PVT reaction time change over the 10-minute task duration?
PVT Over Time

Does PVT reaction time change over the 10-minute task duration?

YES

Altitude: $F(2, 124) = 23.0, p < 0.01$

First vs. Second Half: $F(1, 124) = 10.8, p < 0.01$
PVT Over Time

Does PVT reaction time change over the 10-minute task duration?

YES

Altitude: $F(2, 124) = 23.0$, $p < 0.01$
First vs. Second Half: $F(1, 124) = 10.8$, $p < 0.01$

GL: First $\sim$ Second Half ($p = 0.31$)
14k & 17.8K: First < Second Half ($p < 0.01$)
Conclusions

1. With PHODS during PVT testing, SpO$_2$ fell by about 6% and rSO$_2$ by about 5 units at both 14,000 & 17,800 ft relative to GL.

2. This modest drop occasioned a delay of about 33 ms in PVT reaction times, i.e., a delay of about 10% in the simplest response of the visual system to the onset of a light.

3. If this is indicative of the slowing of neural processing through the central nervous system, the delays may be compounded and possibly disrupt normally synchronous signals and overt behaviors such as those supporting the ocular motor system.

4. Data suggest a cumulative PVT fatigue or tedium at both 14,000 ft and 17,800 ft such that, on average, reaction times recorded during the Second Half of PVT testing were statistically slower than reaction times recorded during for the First Half of PVT testing, an effect not seen at GL possibly indicating a compound hypoxia fatigue effect.
Altitude Chamber Flight Profile & Events

1. Psychomotor Vigilance Test
2. Text reading
3. Squats
4. Ear & sinus check
5. 30 minutes pre breathing
**SpO₂**

<table>
<thead>
<tr>
<th>14,000 ft PA</th>
<th>PVT</th>
<th>TR</th>
<th>WL</th>
</tr>
</thead>
<tbody>
<tr>
<td>17,800 ft PA</td>
<td>PVT</td>
<td>TR</td>
<td>WL</td>
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</table>

**rSO₂**

<table>
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<tr>
<th>14,000 ft PA</th>
<th>PVT</th>
<th>TR</th>
<th>WL</th>
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</thead>
<tbody>
<tr>
<td>17,800 ft PA</td>
<td>PVT</td>
<td>TR</td>
<td>WL</td>
</tr>
</tbody>
</table>
Altitude means

**SpO₂**

Altitude \((F(2, 42) = 31.63, p < 0.01)\), GL > 14K, 17.8K

**rSO₂**

Altitude \((F(2, 42) = 43.47, p < 0.01)\), GL > 14K, 17.8K
Slopes

SpO₂

Altitude (χ² = 5.77, p > 0.05)
Task (χ² = 3.42, p > 0.05)

Altitude x Task (F(4,160) = 2.52, p = 0.04)
Conclusions

SpO₂ (Peripheral blood oxygen saturation) vs. rSO₂ (Regional cerebral blood oxygen)

- PHODS maintained SpO₂ at 14,000 and 17,800 ft:
  a. at adequate levels, albeit at levels lower than expected at MSL (90% < SpO₂ < 97%)
  b. when challenged by speech-imposed interruptions of nasal breathing or 2 minutes of workload rSO₂

- SpO₂ does not predict rSO₂:
  a. rSO₂ fell over time during physical workload (squats) at 14,000 and 17,800 ft
  b. fall-off slope is related directly to altitude; the greater the altitude, the steeper the slope
  c. fall-off time course, severity, practical importance, and recovery are to be determined
  d. need to assess the effect of longer duration workload

Summary

- PHODS has shortcomings as a hypoxia countermeasure
- Recommend enhancements for future Army aircraft particularly when workload is involved
Thank You for Your Attention.

Questions, Comments?
<table>
<thead>
<tr>
<th>Min (Clock)</th>
<th>Altitude</th>
<th>Event</th>
<th>Nasal Can</th>
<th>Aviator Mask</th>
<th>OFF</th>
<th>R/M</th>
<th>ON</th>
<th>F2O PHODS Mask</th>
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<tr>
<td>45</td>
<td>GL</td>
<td>Verbal Briefs (USAARL SAAM)</td>
<td>x</td>
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<td></td>
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<tr>
<td>35</td>
<td>GL</td>
<td>Participant Signatures</td>
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<td></td>
<td></td>
<td>x</td>
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<tr>
<td>30</td>
<td>GL</td>
<td>Equip prep (helmet mods, instrument participants), etc</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>GL</td>
<td>PHODS Ground Check</td>
<td>x</td>
<td>x</td>
<td></td>
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</tr>
<tr>
<td>2</td>
<td>GL</td>
<td>PVT (10 mins)</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>GL</td>
<td>Script (5 mins)</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>17</td>
<td>GL</td>
<td>Workload (2 mins)</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
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<tr>
<td>19</td>
<td>GL, 3K, GL</td>
<td>Ear and sinus check</td>
<td>x</td>
<td>x</td>
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<td></td>
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<tr>
<td>21</td>
<td>14000</td>
<td>Ascent to 14K (~1,000 fps)</td>
<td>x</td>
<td>x</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>14000</td>
<td>5 min Acclimation</td>
<td>x</td>
<td>x</td>
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<tr>
<td>40</td>
<td>14000</td>
<td>PVT (10 mins)</td>
<td>x</td>
<td>x</td>
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<tr>
<td>50</td>
<td>14000</td>
<td>Script (5 mins)</td>
<td>x</td>
<td>x</td>
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<tr>
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<td></td>
<td></td>
<td>x</td>
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</tr>
<tr>
<td>57</td>
<td>14000</td>
<td>Participants switch to chamber O2 x 30 min</td>
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<td></td>
<td></td>
<td>x</td>
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<tr>
<td>87</td>
<td>14000</td>
<td>Ascent to 17.8K (~1,000 fps)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>91</td>
<td>17800</td>
<td>5 min Acclimation (don PHODS helmet for communication)</td>
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<td>No supplemental oxygen</td>
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<tr>
<td>96</td>
<td>17800</td>
<td>1 min Acclimation to NC</td>
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<td></td>
<td>x</td>
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<td>112</td>
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<td>114</td>
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Fort Rucker, Alabama

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