USAARL-CNPA-BC--2022-25

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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14. ABSTRACT

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.

15. SUBJECT TERMS

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

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14. Abstract (continued)
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, PhD[1], Bobby Bowers[1], Amanda Hayes[1], MS, Paul St. Onge, PhD[1], Aaron McAtee, MS[1,2], LTC Frank Petrassi, PhD[3], Dennis Ard[3]

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[2]Goldbelt Frontier, Alexandria, VA
[3]School of Army Aviation Medicine, Fort Rucker, AL

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Problem Statement

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

Army Regulation 95-1 Flight Regulations: Chapter 8 Aviation Life Support

"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.

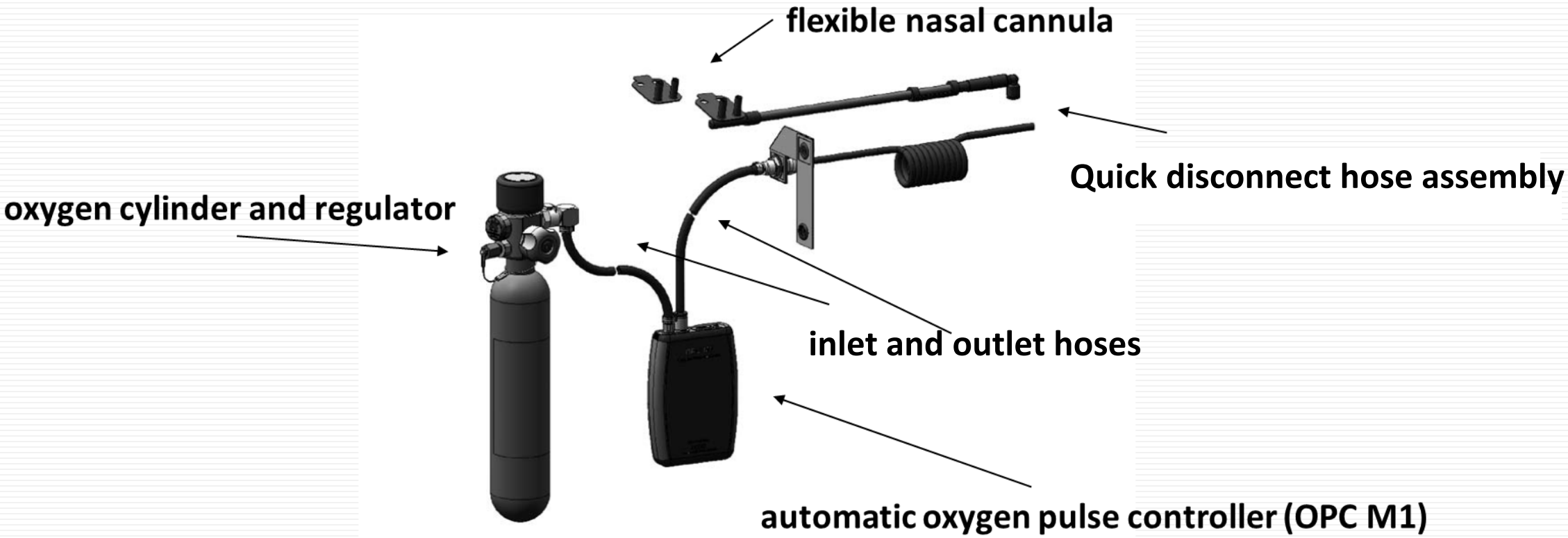
(a) On flights above 14,000 feet pressure altitude for any period of time

(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



Note: Crewmember mask not depicted

PHODS Oxygen Pulse Controller (OPC M1)

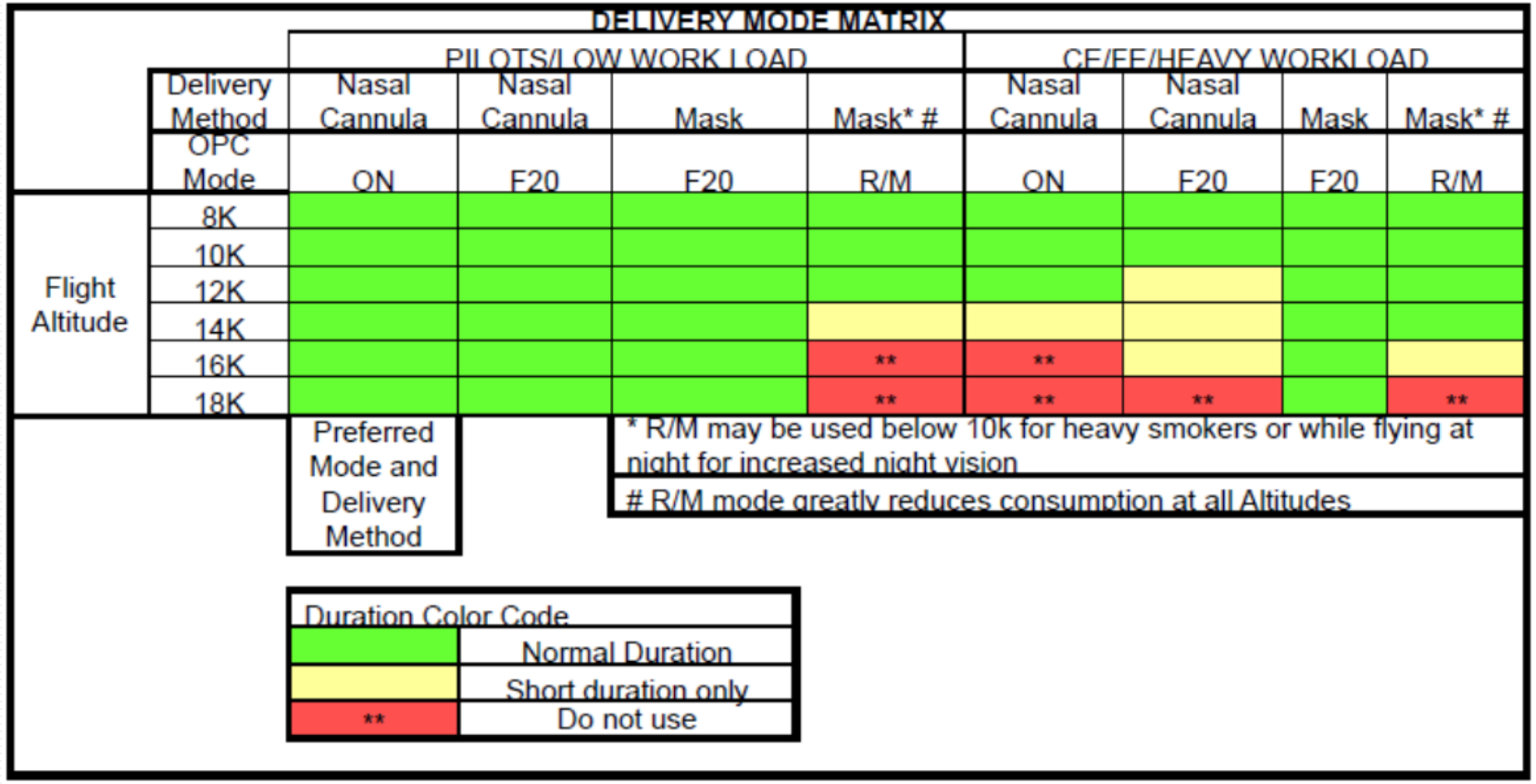
Oxygen Pulse Controller (OPC M1)

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



DELIVERY MODE MATRIX

		PILOTS/LOW WORK LOAD				CF/FF/HEAVY WORKLOAD			
	Delivery Method	Nasal Cannula	Nasal Cannula	Mask	Mask* #	Nasal Cannula	Nasal Cannula	Mask	Mask* #
	OPC Mode	ON	F20	F20	R/M	ON	F20	F20	R/M
Flight Altitude	8K								
	10K								
	12K								
	14K								
	16K				**	**			
	18K				**	**	**		**

Preferred Mode and Delivery Method

* R/M may be used below 10k for heavy smokers or while flying at night for increased night vision

R/M mode greatly reduces consumption at all Altitudes

Duration Color Code	
	Normal Duration
	Short duration only
**	Do not use

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)

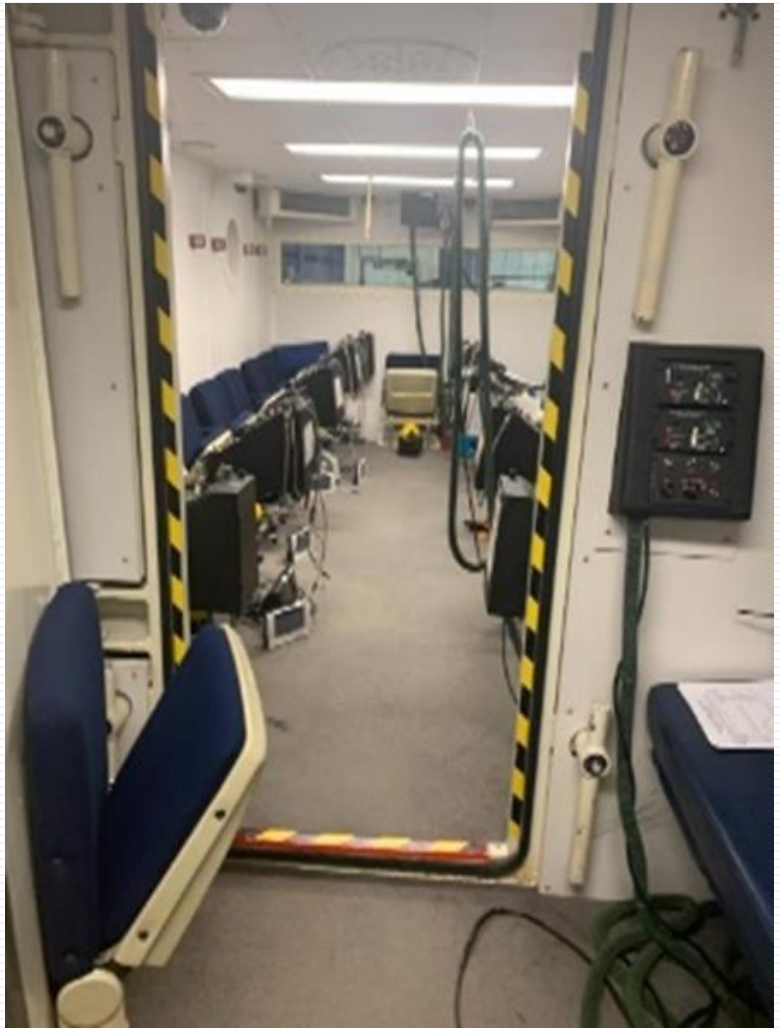
Tasks / Challenges

- 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 (SpO_2) (continuous)
  - NONIN Life Sense Model LS1-9R
- Near Infrared Transcranial Spectroscopy (NIRS) (rSO_2) (continuous)
  - NONIN Equanox Model 7600
- PVT Performance (visual reaction time in milliseconds [ms])

School of Army Aviation Medicine Altitude Chamber



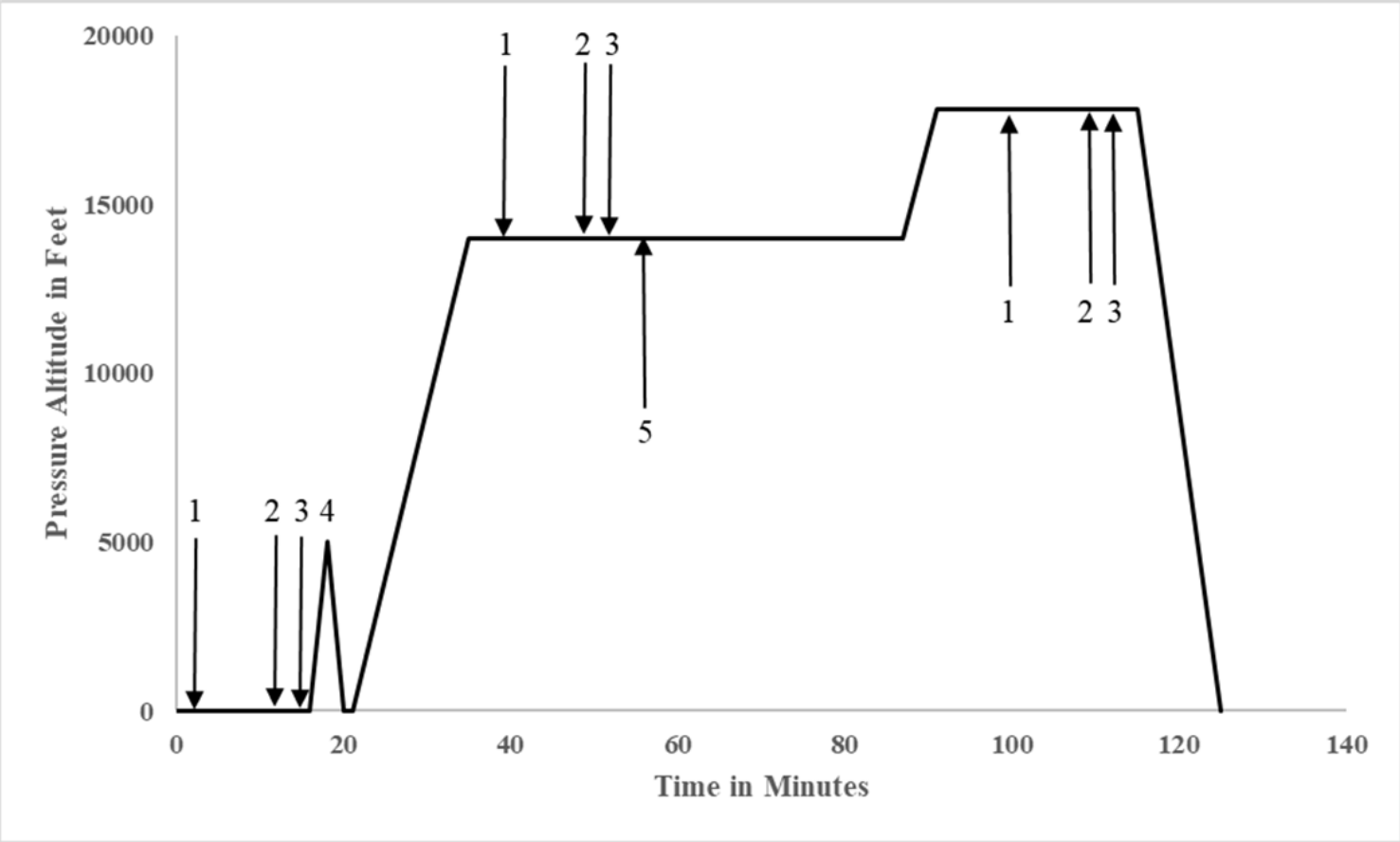
Altitudes tested

- 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

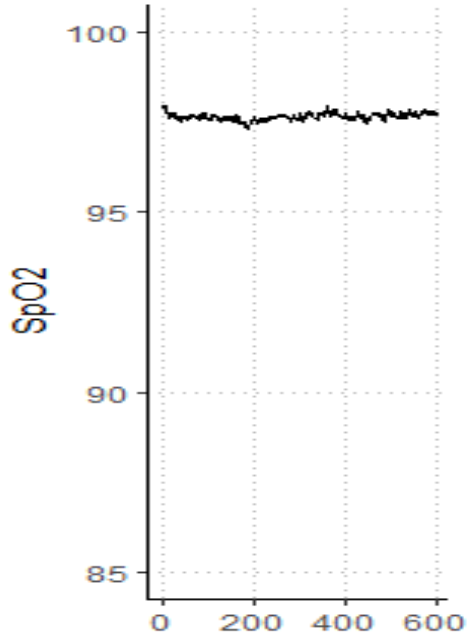
Altitude Chamber Flight Profile & Events



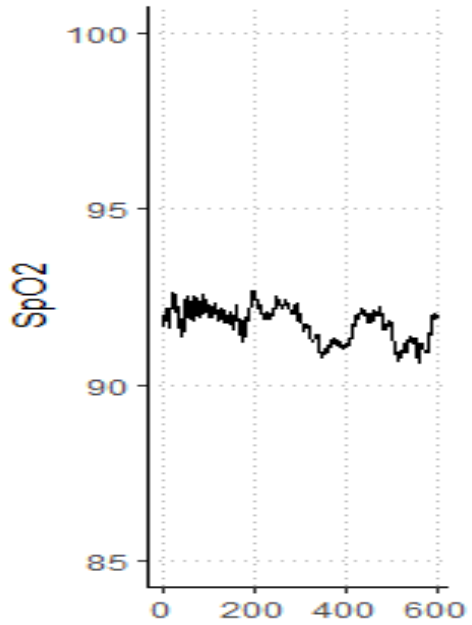
1. **PVT**
2. Text reading
3. Squats
4. Ear & sinus check
5. 30 minutes pre-breathing

SpO_2 during PVT

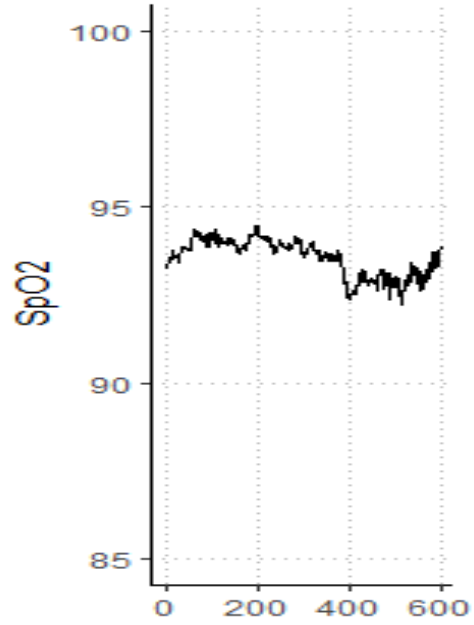
Ground Level



14,000 ft



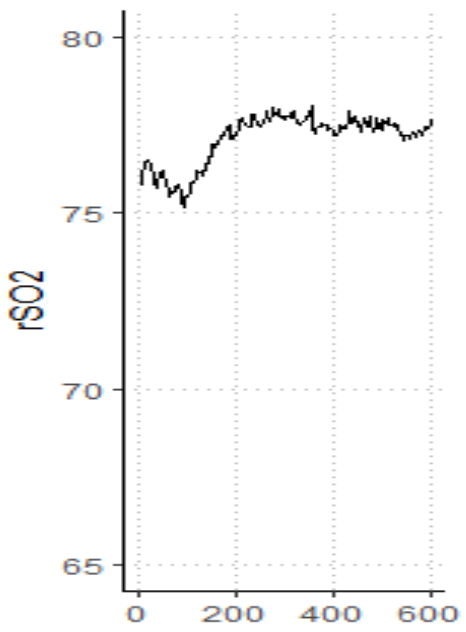
17,800 ft



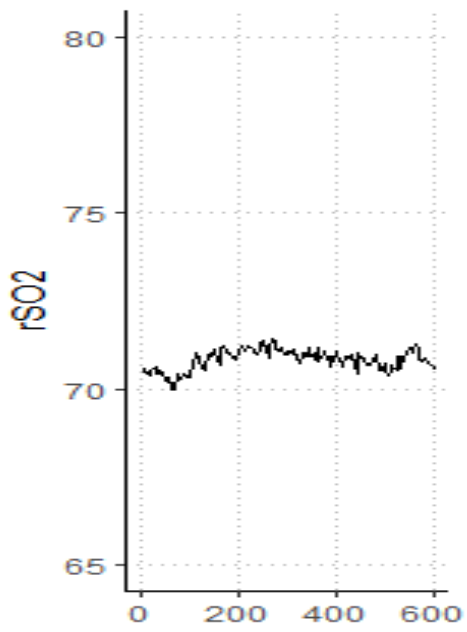
Time (10 minutes)

rSO_2 during PVT

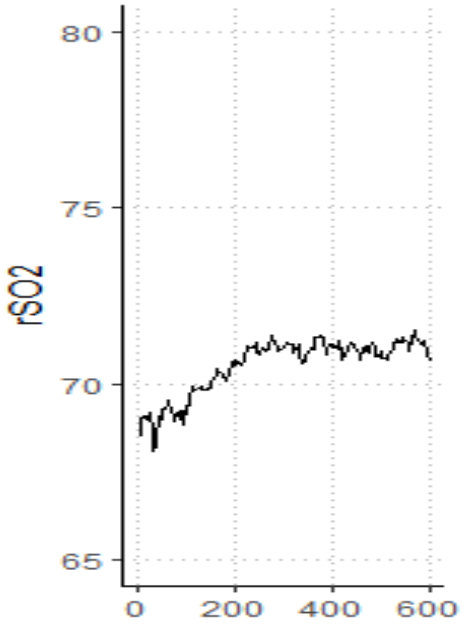
Ground Level



14,000 ft

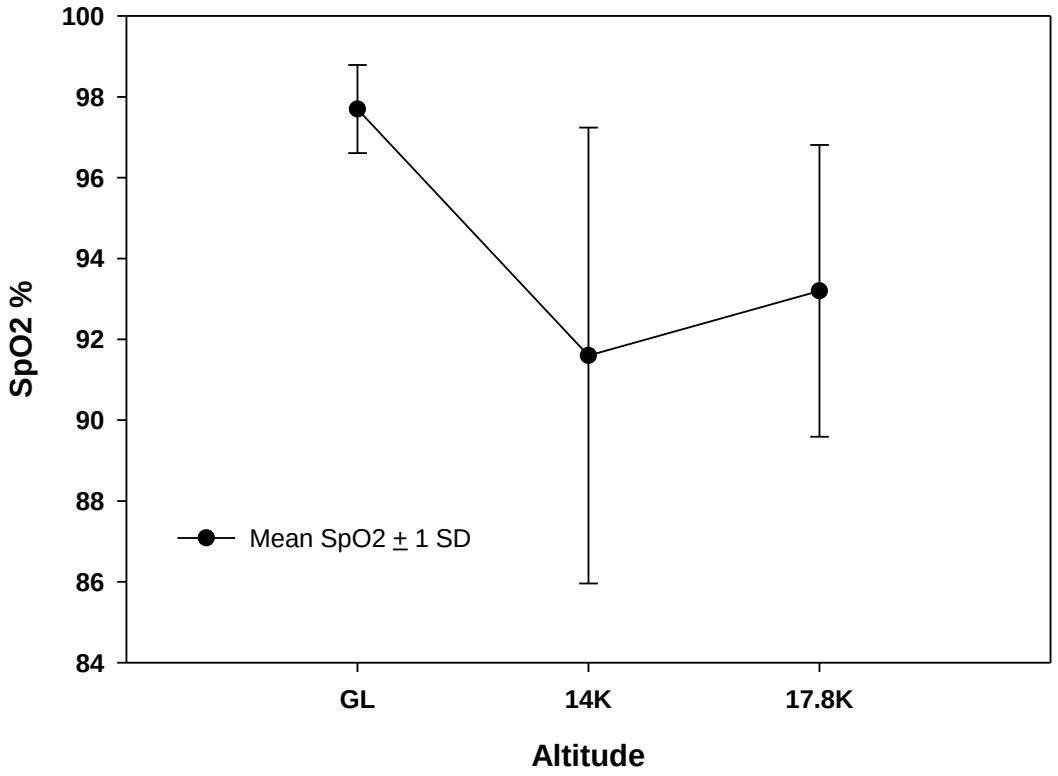


17,800 ft

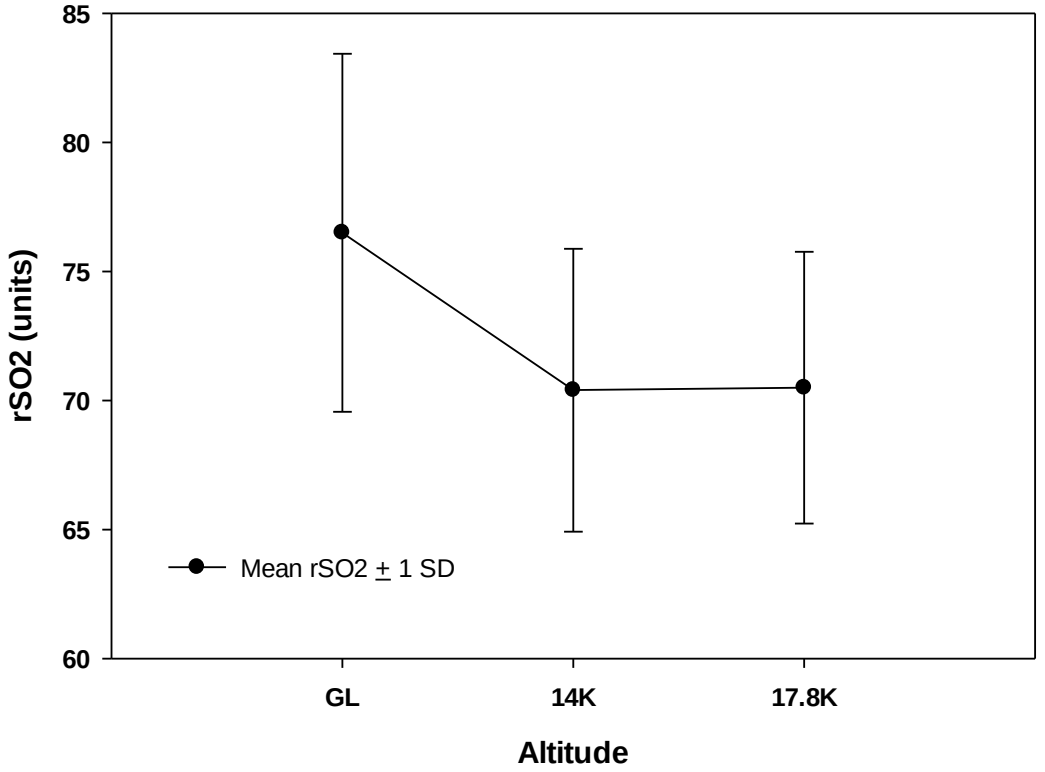


Time (10 minutes)

Mean SpO_2 & rSO_2 During PVT (10 minutes)



Mean SpO_2
Altitude ($F(2, 42) = 31.63$, $p < 0.01$)
SpO_2 GL > 14K & 17.8K, $p < 0.01$



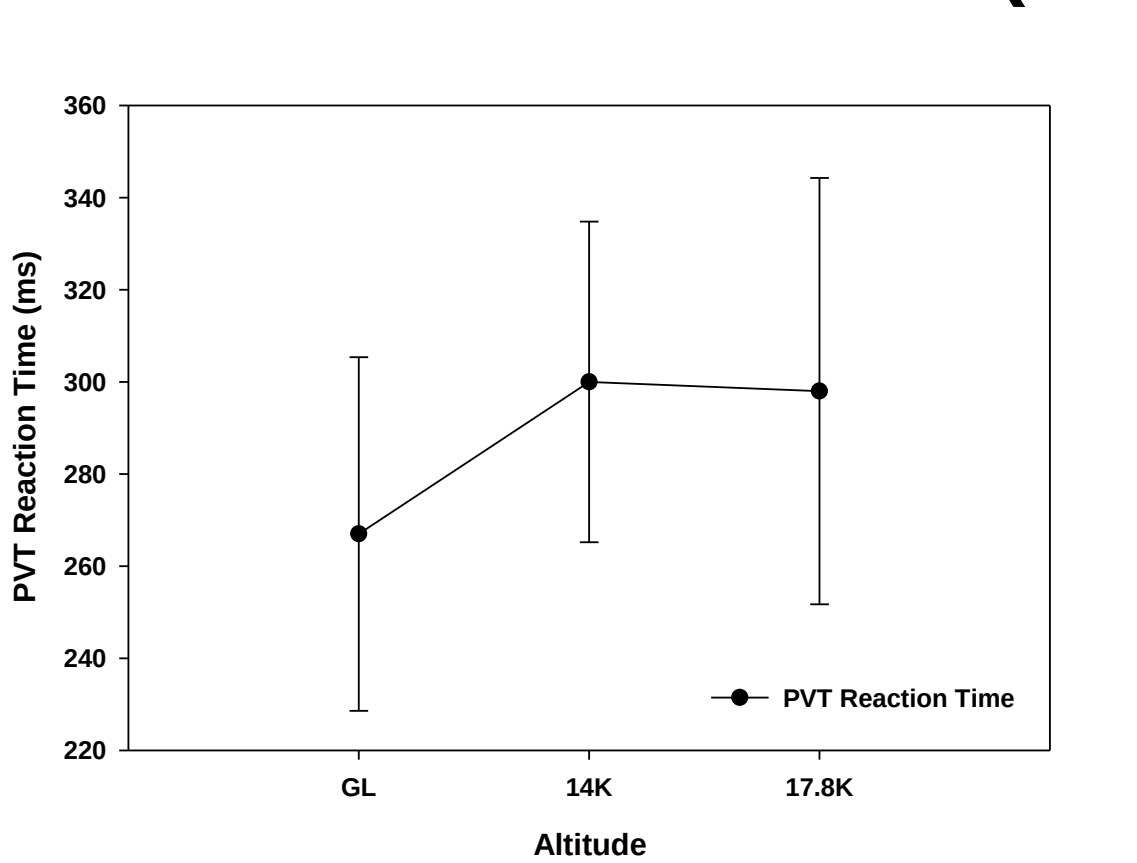
Mean rSO_2
Altitude ($F(2, 42) = 43.47$, $p < 0.01$)
rSO_2 GL > 14K & 17.8K, $p < 0.01$

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.

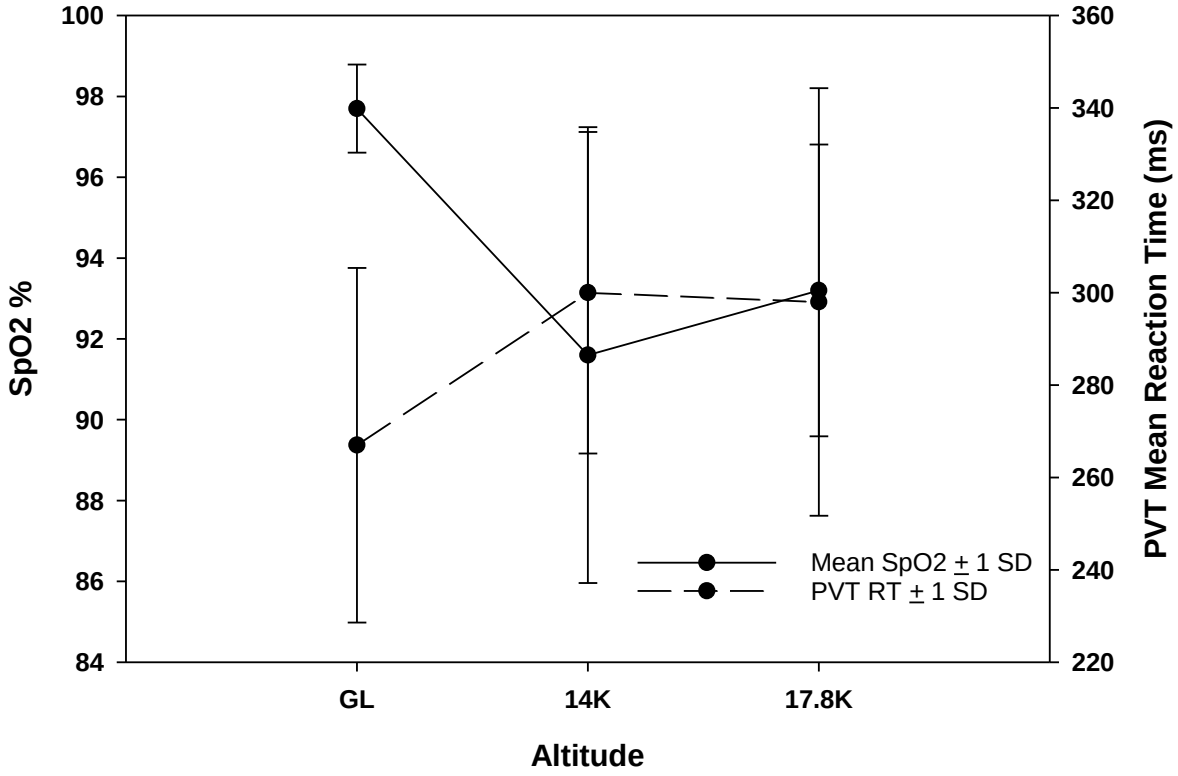
On average, the database recorded 100 such reaction times (RT) for each trial.

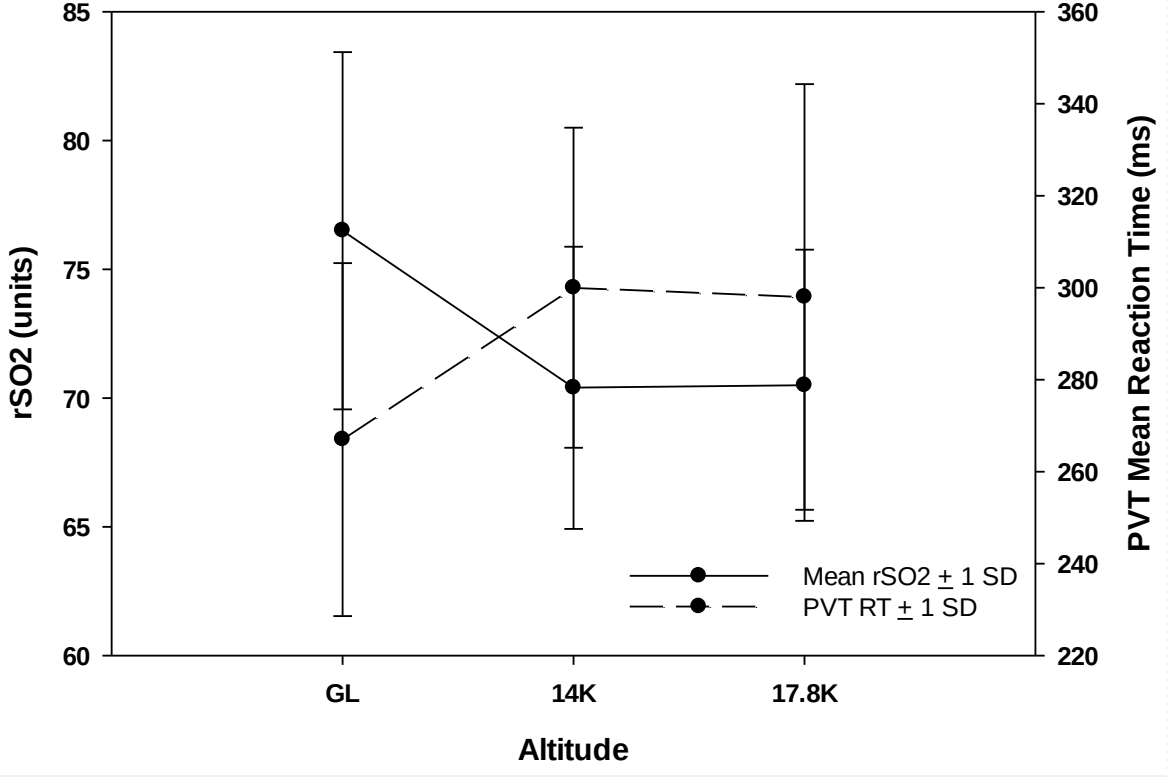
Mean PVT Reaction Time (ms)



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 SpO_2 & rSO_2





PVT Over Time

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

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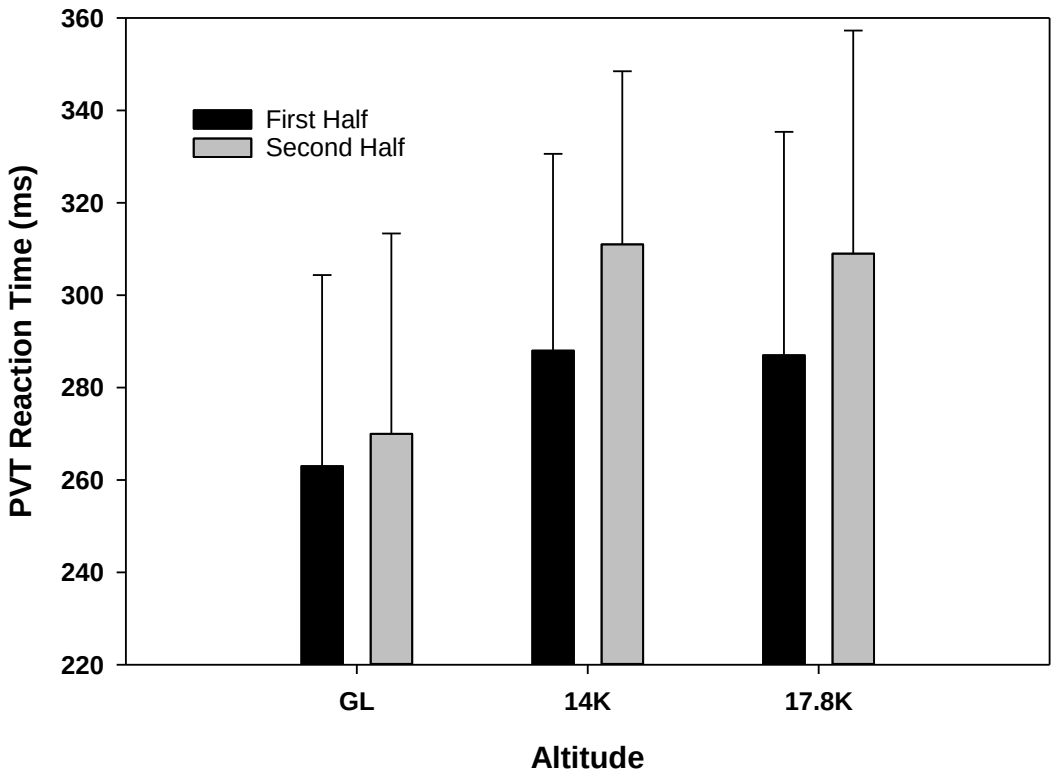
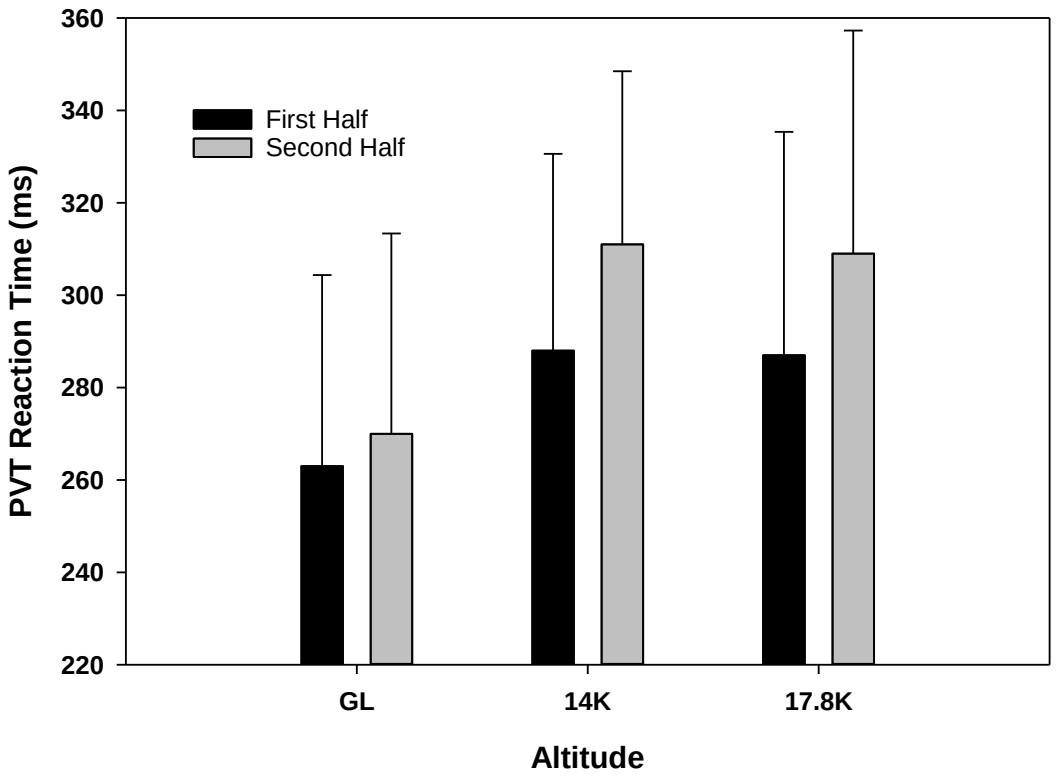


YES

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

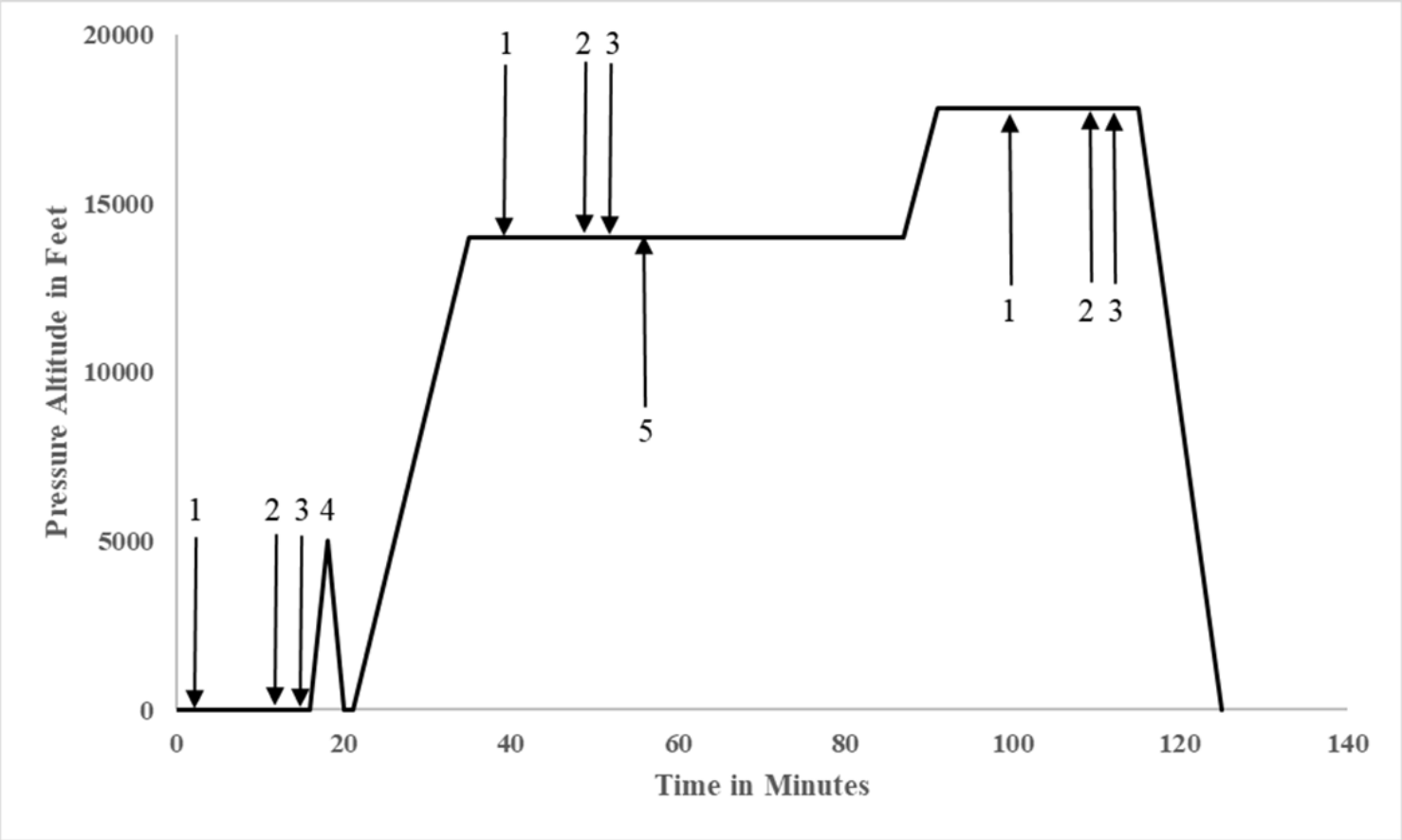
Altitude: $F(2, 124) = 23.0$, $p < 0.01$
First vs. Second Half: $F(1, 124) = 10.8$, $p < 0.01$

GL: First ≃ 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.

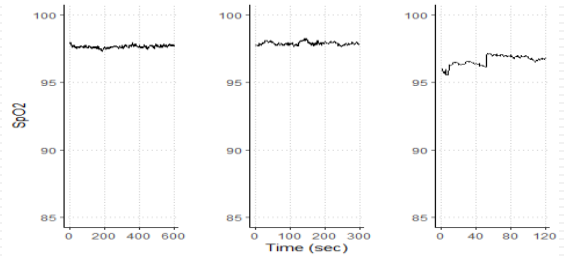
Altitude Chamber Flight Profile & Events



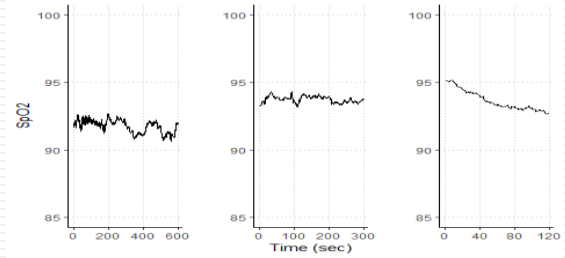
1. Psychomotor Vigilance Test
2. Text reading
3. Squats
4. Ear & sinus check
5. 30 minutes pre breathing

SpO_2

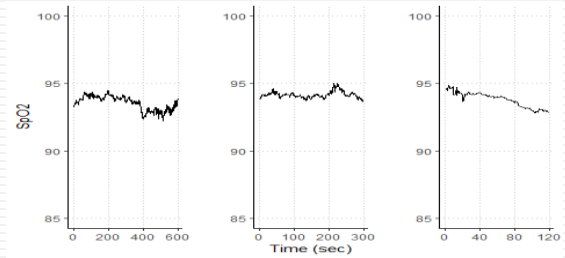
GL PVT TR WL



14,000 ft PA PVT TR WL

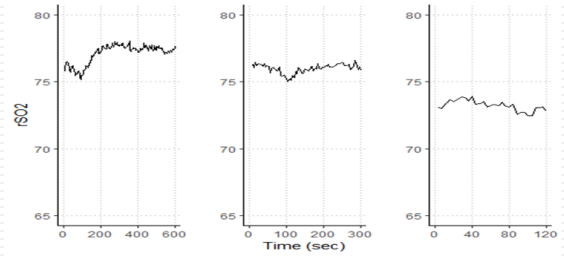


17,800 ft PA PVT TR WL



rSO_2

GL PVT TR WL



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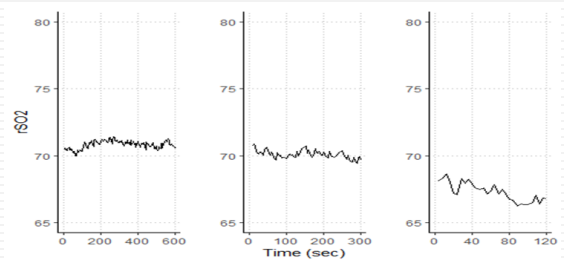
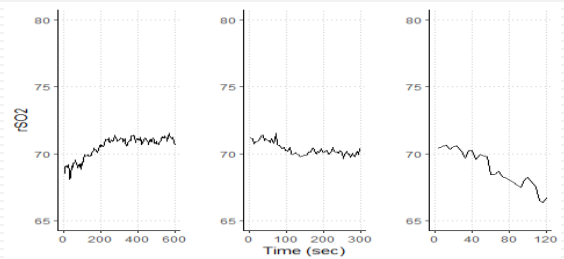
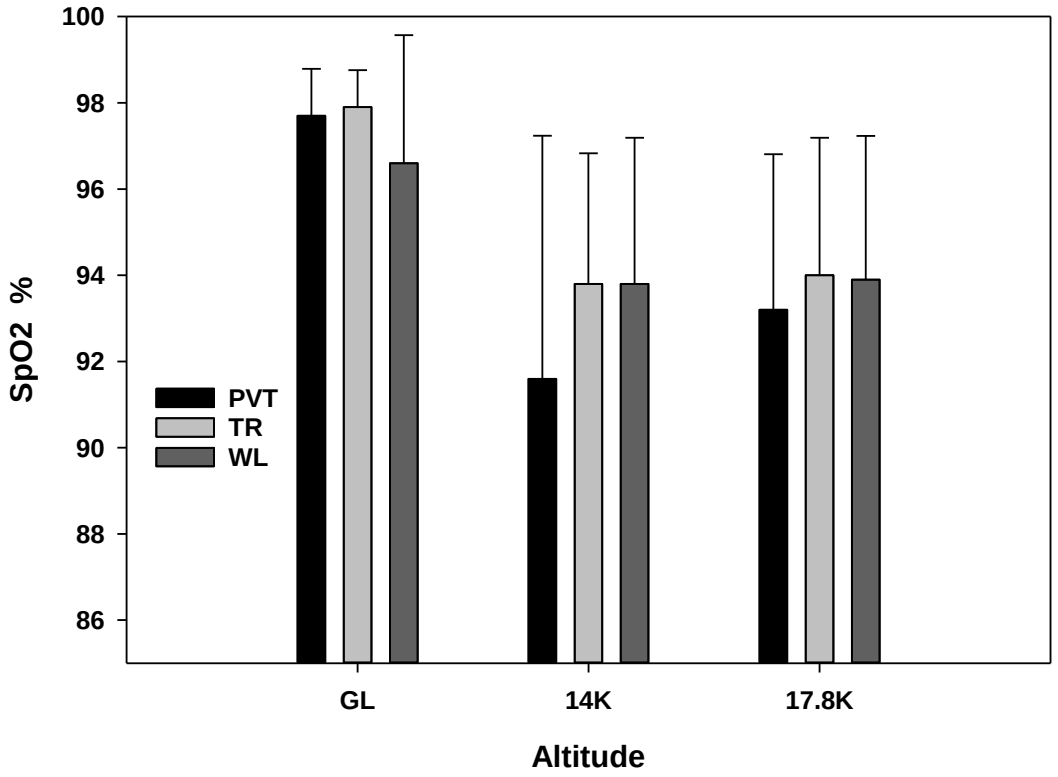


17,800 ft PA PVT TR WL



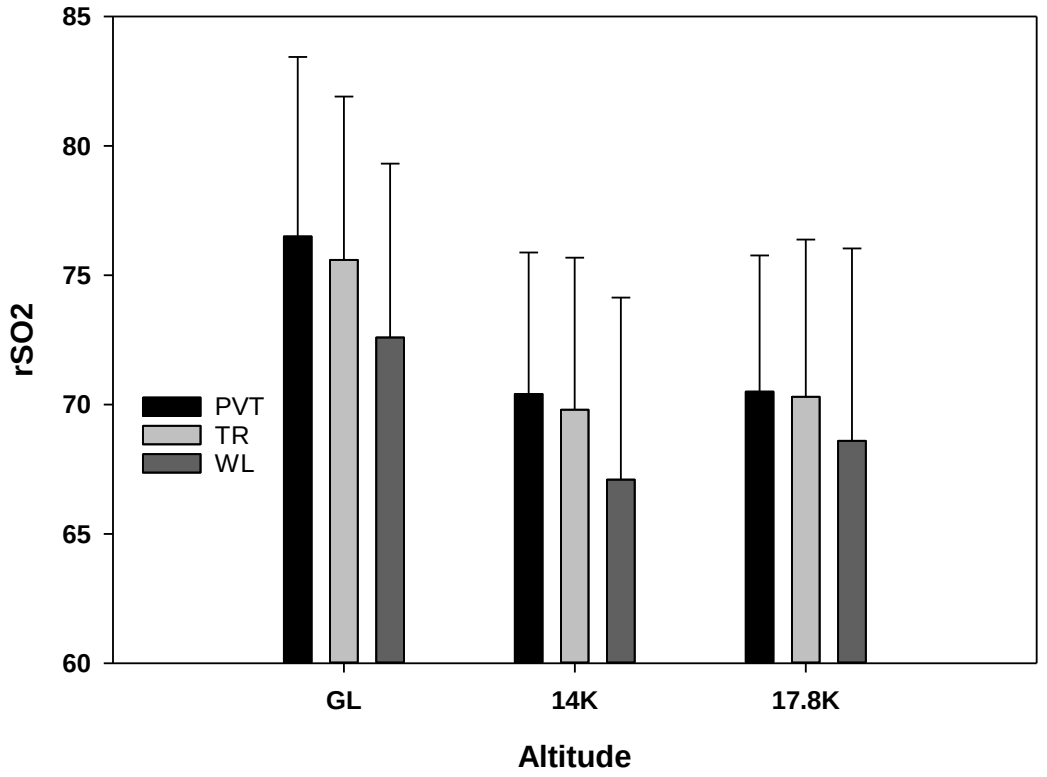
Means

SpO_2



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

rSO_2



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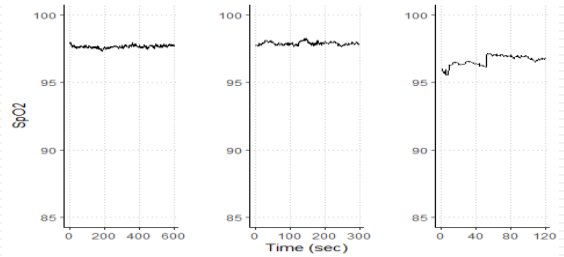
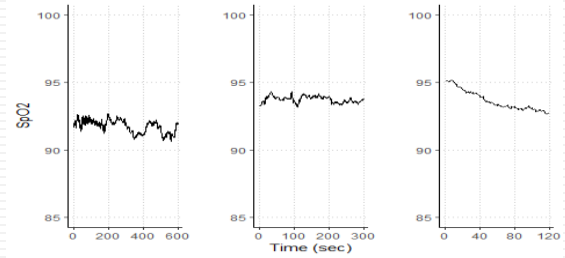
SpO_2

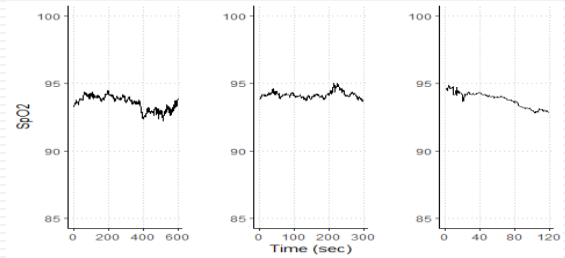
GL PVT TR WL



14,000 ft PA PVT TR WL

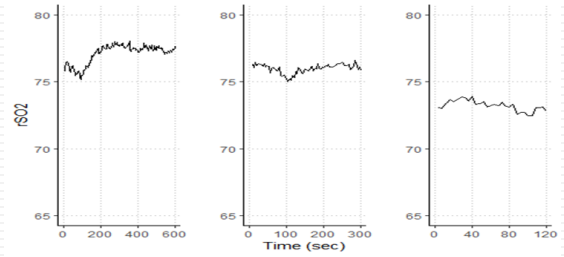


17,800 ft PA PVT TR WL

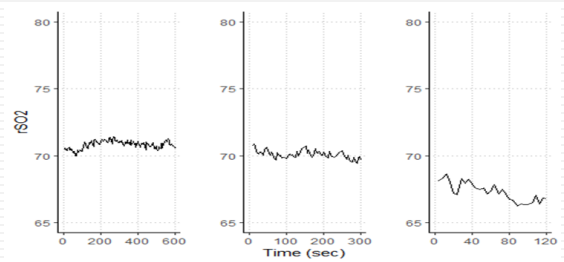


rSO_2

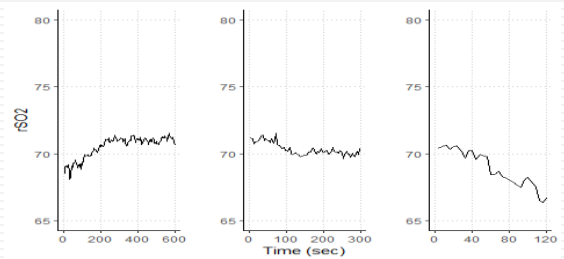
GL PVT TR WL



14,000 ft PA PVT TR WL

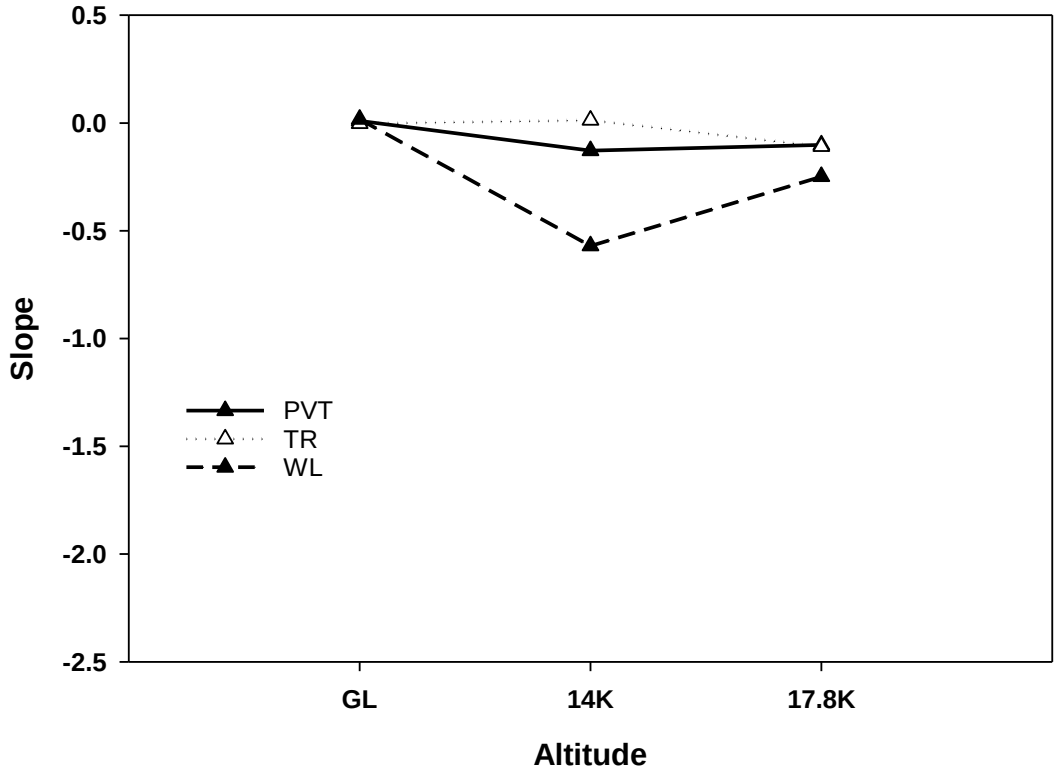


17,800 ft PA PVT TR WL



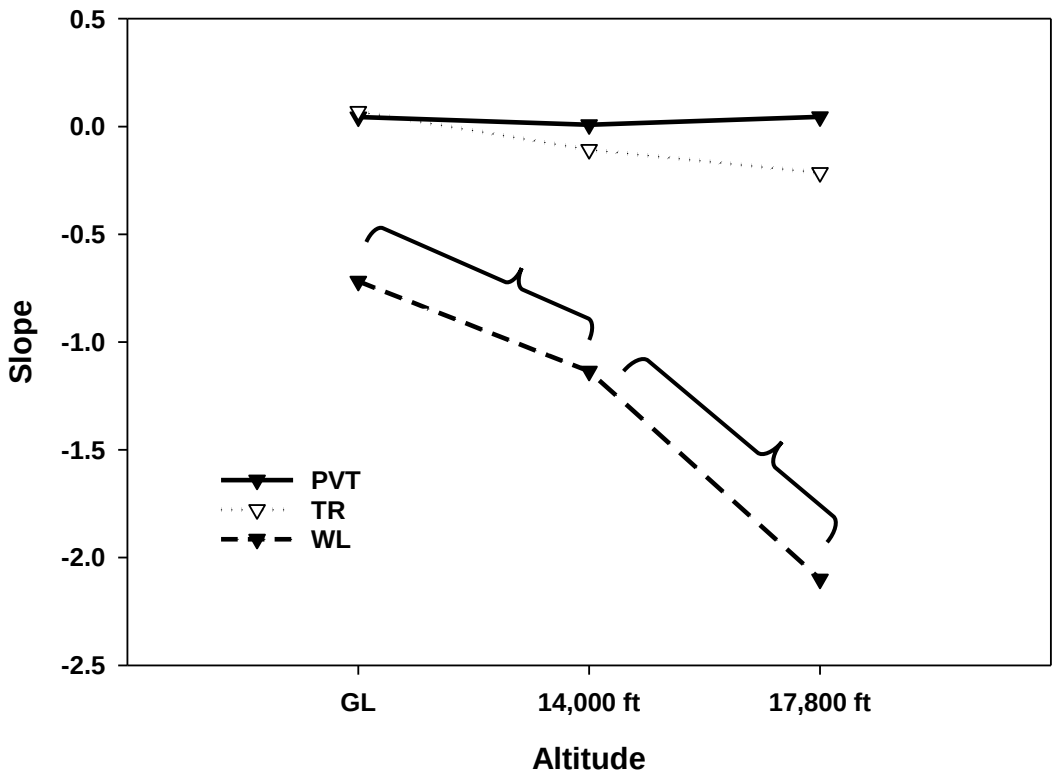
Slopes

SpO_2



Altitude ($\chi^2 = 5.77$, $p > 0.05$)
Task ($\chi^2 = 3.42$, $p > 0.05$)

rSO_2



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

Conclusions

SpO_2 (Peripheral blood oxygen saturation) vs.rSO_2 (Regional cerebral blood oxygen)

- PHODS maintained SpO_2 at 14,000 and 17,800 ft:
  a. at adequate levels, albeit at levels lower than expected at MSL (90%< SpO_2 < 97%)
  b. when challenged by speech-imposed interruptions of nasal breathing or 2 minutes of workload rSO_2
- SpO_2 does not predict rSO_2:
  a. rSO_2 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?

Min (Clock)	Altitude	Event	Nasal Can	Aviator Mask	OFF	R/M	ON	F20 PHODS Mask
-45	GL	Verbal Briefs (USAARL/SAAM)			x			
-35	GL	Participant Signatures			x			
-30	GL	Equip prep (helmet mods, instrument participants), etc.			x			
1	GL	PHODS Ground Check	x			x		
2	GL	PVT (10 mins)	x		x			
12	GL	Script (5 mins)	x		x			
17	GL	Workload (2 mins)	x		x			
19	GL, 5K,GL	Ear and sinus check	x				x	
21	14000	Ascent to 14K (~1,000 fpm)	x				x	
35	14000	5 min Acclimation	x				x	
40	14000	PVT (10 mins)	x				x	
50	14000	Script (5 mins)	x				x	
55	14000	Workload (2 mins)						x
57	14000	Participants switch to chamber O2 x 30 min Hypoxia Questionnaire		x				
87	14000	Ascent to 17.8K (~1,000 fpm)		x				
91	17800	5 min Acclimation (don PHODS helmet for communication)	**No supplemental oxygen**					
96	17800	1 min Acclimation to NC	x				x	
97	17800	PVT (10 mins)	x				x	
107	17800	Script (5 mins)	x				x	
112	17800	Workload (2 mins)						x
114	↓GL	Hypoxia Questionnaire						x

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All of USAARL's science and technical information documents are available for download from the Defense Technical Information Center.

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