Assessment of Physiologic Monitors for Measurement of Heart Rate During Experimental Diving Operations

Photo by PO2Moises Sandoval, VIRIN: 260415-N-ED646-2051

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August 06, 2026

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The study protocol was approved by the Navy Experimental Diving Unit Institutional Review Board in compliance with all applicable Federal regulations governing the protection of human subjects. Research data were derived from an approved Navy Experimental Diving Unit Institutional Review Board protocol, number 25-13.

Introduction

U.S. Navy diving operations can be dangerous and occur in extreme environments

- Sub-zero temperatures & polar Ice
- Deep-sea hyperbaric pressure
- Dark or low visibility

The more extreme the environment, the higher the risk for diving related disorders and illnesses

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Introduction

Monitoring vital signs in real time can help identify a problem early and reduce the risk of a casualty

- Peripheral Oxygen Saturation (SpO_2)
- Heart Rate (HR)

Measuring vital signs such as HR can be a challenge due to variances that can affect performance monitoring

- Aqueous environment (water intrusion)
- Diving equipment
- Hyperbaric pressure

The United States Military currently lacks the capability to monitor physiological status and health of divers during training and operational scenarios

Determine the capability of three different prototype devices that measure HR while submerged in water at different depths and breathing gases with 21% and 13% O_2.

Three Tested Prototypes

Designed to measure oxygenated and deoxygenated hemoglobin for changes in SpO_2 and HR using Photoplethysmography (PPG)

1. Wrist

- Wrist worn monitor connected to a single finger cuff
  - Worn like a glove
- Monitor on the wrist displays physiological output real time

2. Ear

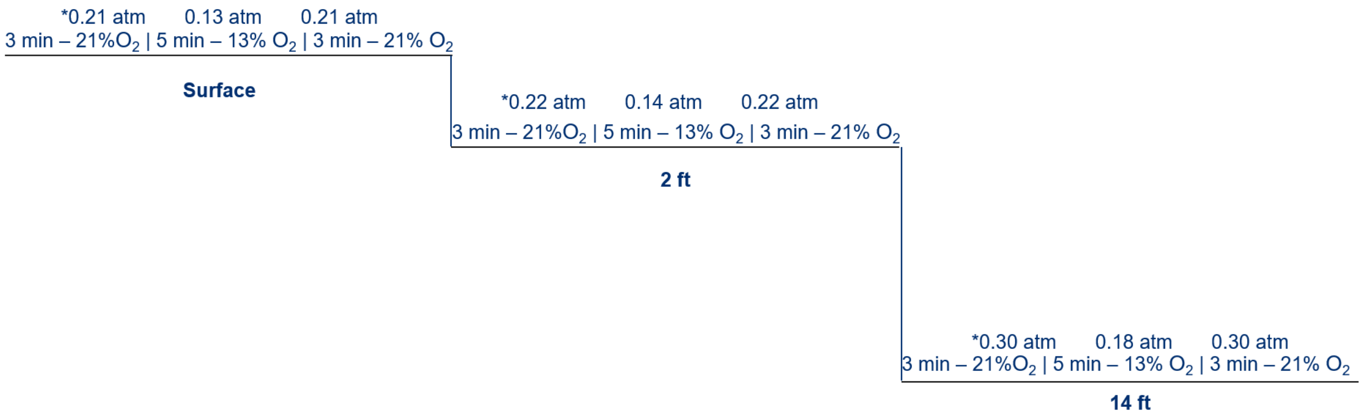
- Outer ear canal monitor
  - Custom mold allowed the monitor to contour to each person
- Communicated through a watch worn on the wrist
  - Vibration alert if the participant’s physiological measurements reach a potentially dangerous threshold

3. Arm

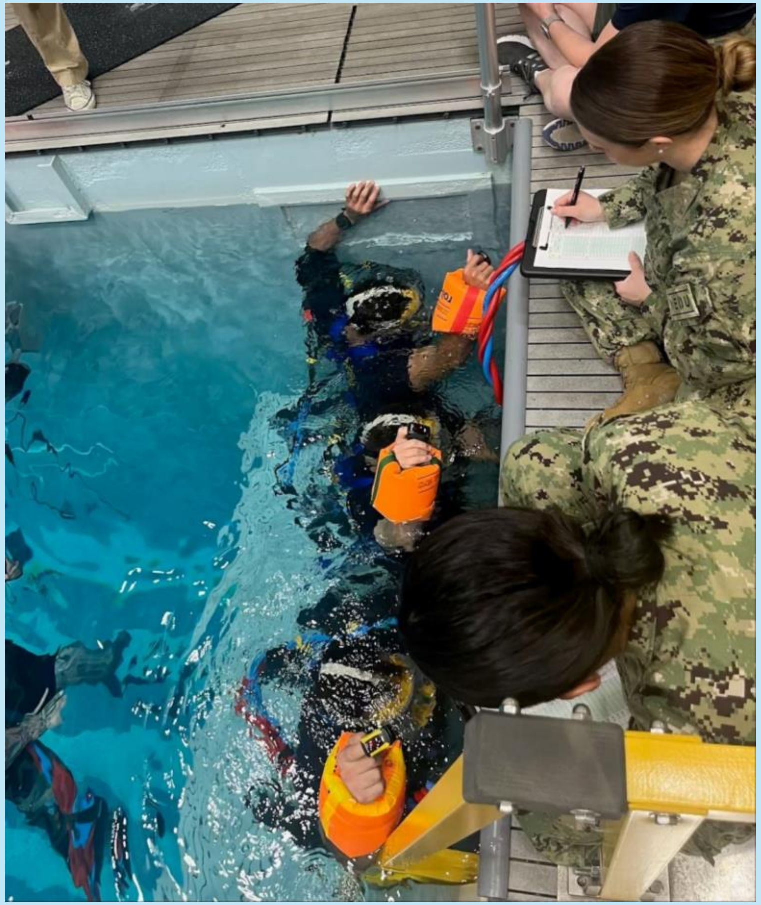
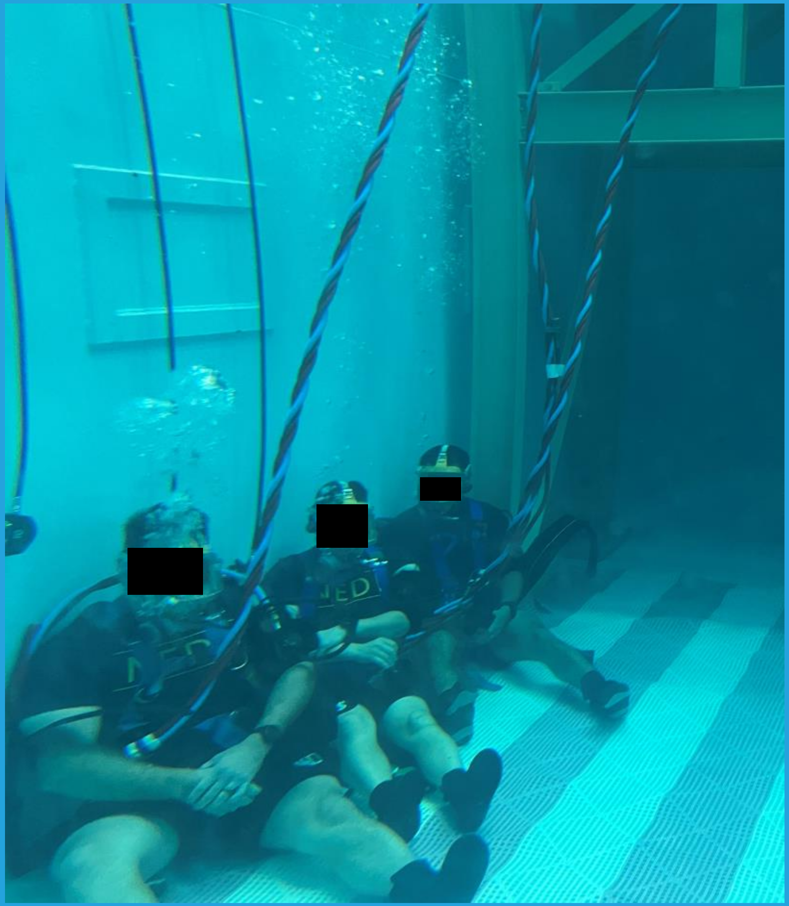
- Upper arm monitor worn around the bicep on the brachial artery
- Transmitted through acoustic communication to relay top-side onto a computer screen
  - Aims to provide real time readings
  - Alerts top-side if physiological readings reach a potentially dangerous threshold

Methods

- Measurements collected under three ambient pressure conditions while resting:
  - Surface: Dry on surface
  - 2 ft: submersed at two feet of fresh water
  - 14 ft: submerged at 14 feet of fresh water
- Each ambient pressure interval lasted for 11 minutes.
  - 3 min at 21% O_2, 5 min at 13% O_2, 3 min at 21% O_2
- During each interval, subjects breathed gases with different partial pressures of oxygen (ppO_2) via a surface supplied full face mask.
  - All gas was balanced with nitrogen



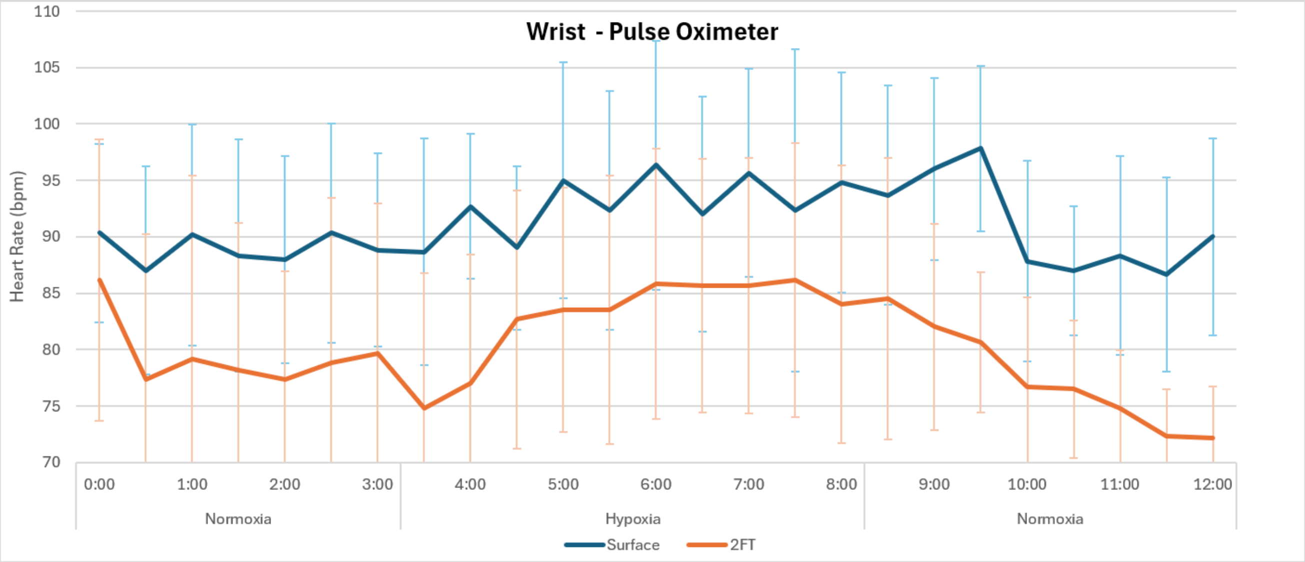
*partial pressure of oxygen (ppO_2)

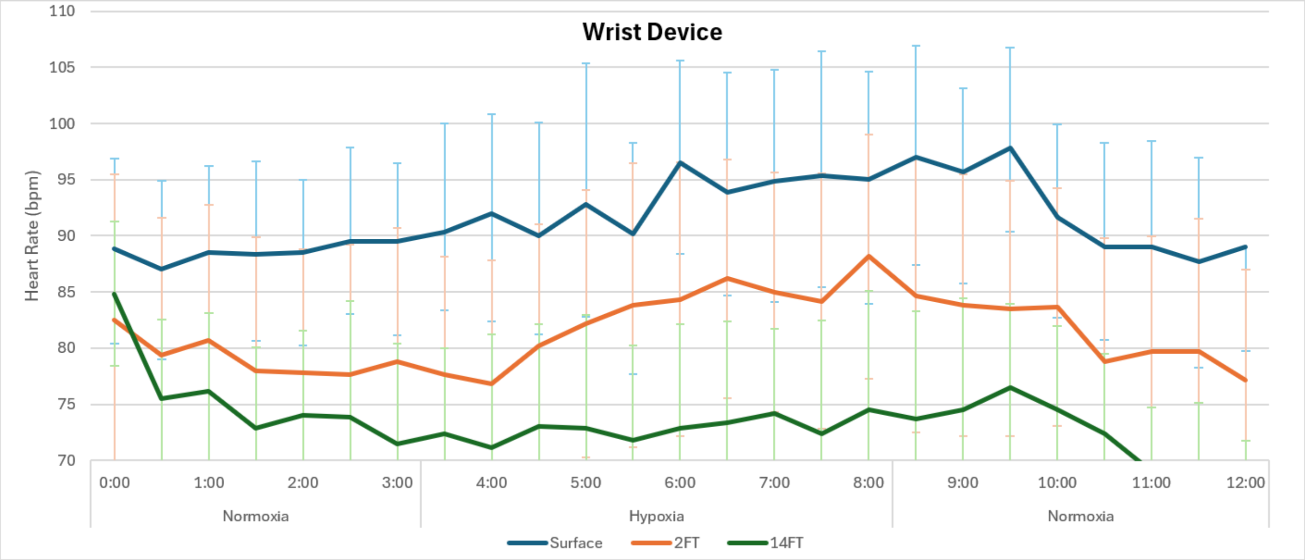
Surface	2 ft	14 ft
		

Photos by Nicole Stavitzski, PhD

Surface and 2 ft levels were utilizing a finger pulse oximeter (Nonin) to verify hypoxic gas breathing was influencing HR, as previous research has indicated.

Results - Wrist





Data presented as mean±SD

Pulse Oximeter

Surface: 21% to 13% O_2
90±9 BPM to 95±10 BPM

2 ft: 21% to 13% O_2
79±14 BPM to 84±12 BPM

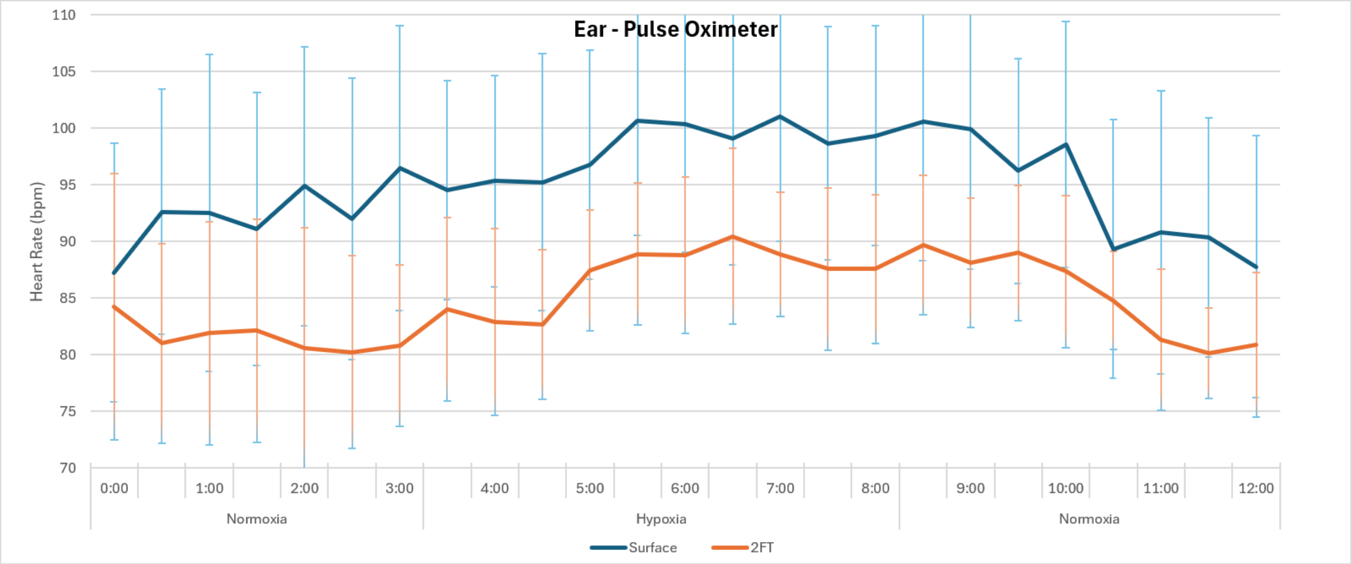
Wrist Device

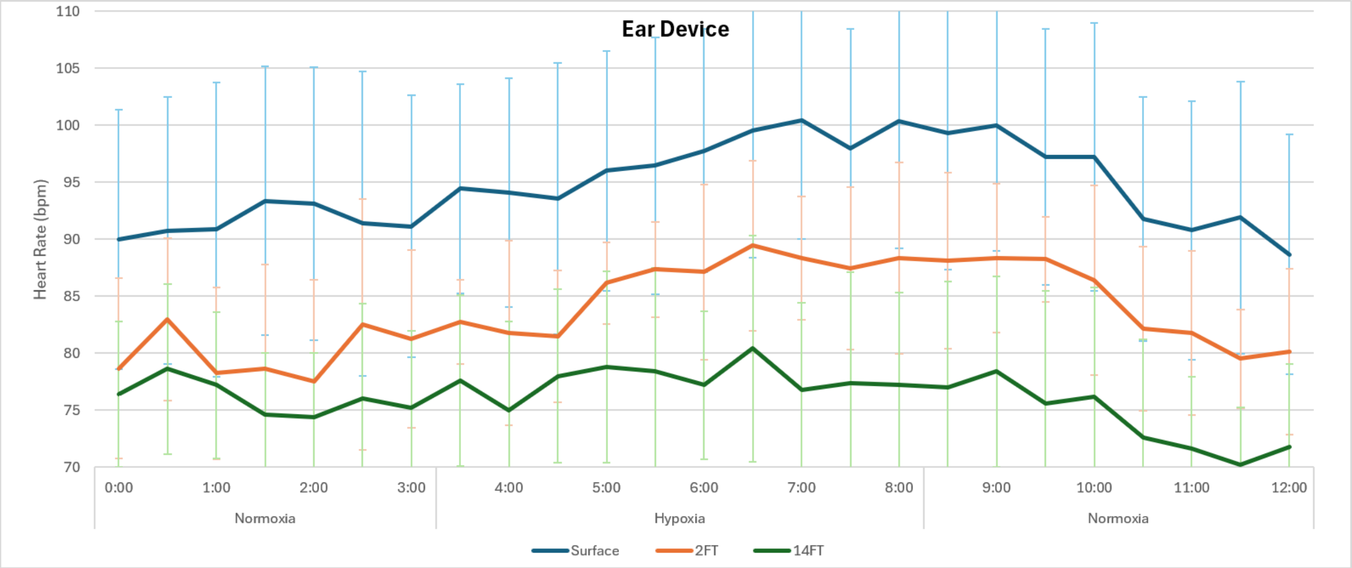
Surface: 21% to 13% O_2
88±7 BPM to 93±9 BPM

2 ft: 21% to 13% O_2
79±11 BPM to 83±11 BPM

14 ft: 21% to 13% O_2
75±7 BPM to 72±9 BPM

Results - Ear





Data presented as mean±SD

Pulse Oximeter

Surface: 21% to 13% O2
94±12 BPM to 100±11 BPM

2 ft: 21% to 13% O2
81±8 BPM to 89±6 BPM

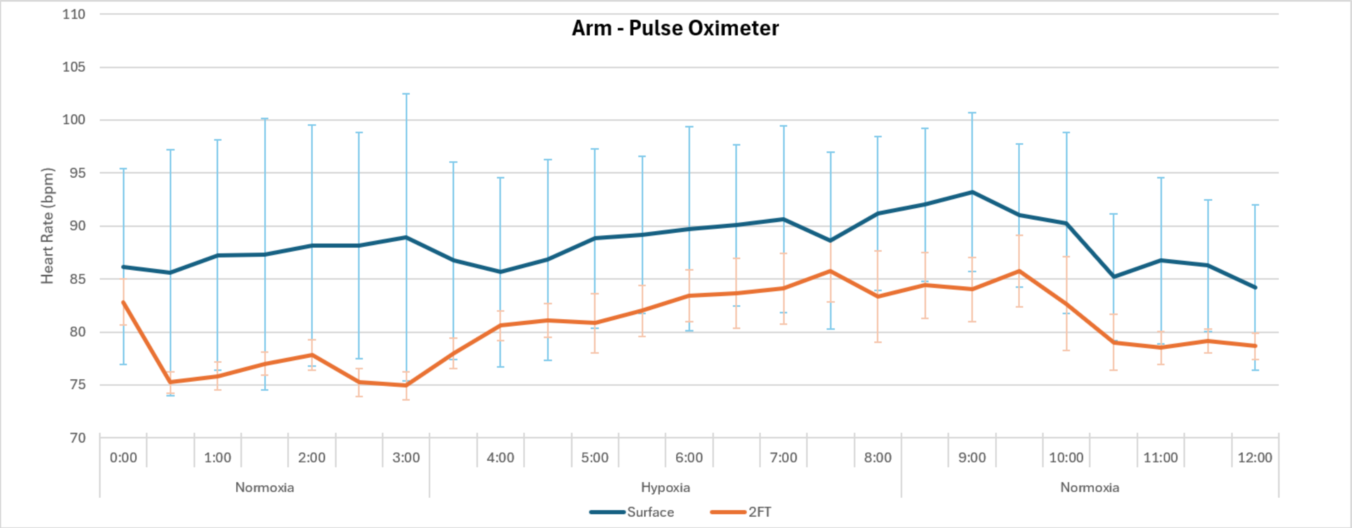
Ear Device

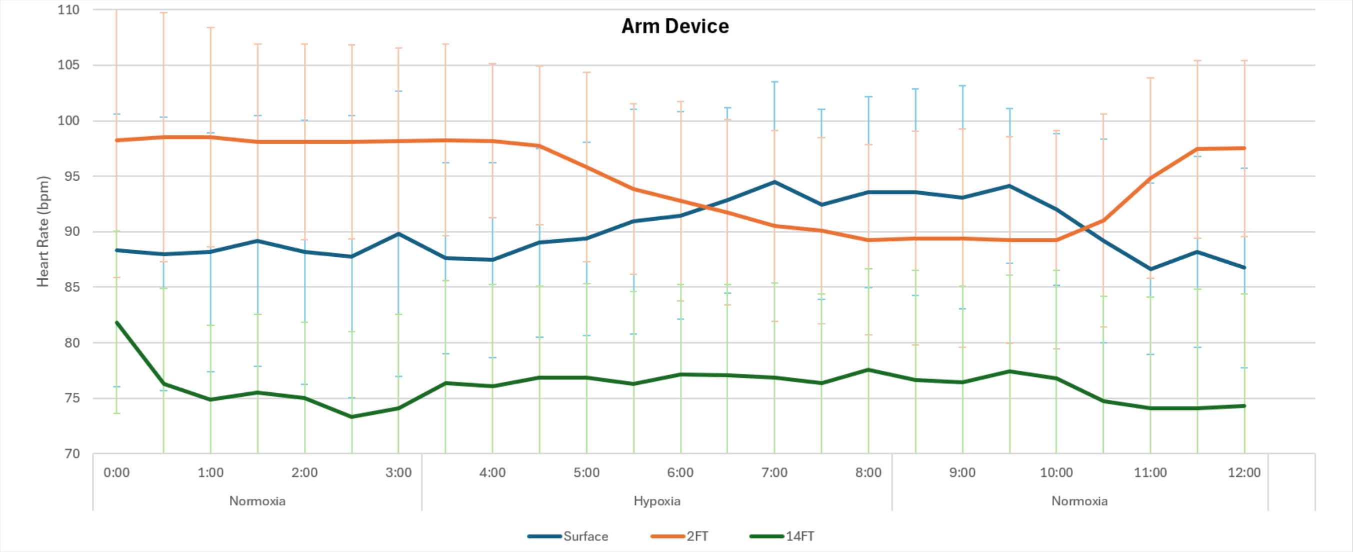
Surface: 21% to 13% O2
92±12 BPM to 97±11 BPM

2 ft: 21% to 13% O2
80±8 BPM to 86±6 BPM

14 ft: 21% to 13% O2
76±7 BPM to 78±8 BPM

Results - Arm





Data presented as mean±SD

Pulse Oximeter

Surface: 21% to 13% O2
89±12 BPM to 92±7 BPM

2 ft: 21% to 13% O2
75±8 BPM to 84±8 BPM

Arm Device

Surface: 21% to 13% O2
88±12 BPM to 93±9 BPM

2 ft: 21% to 13% O2
77±10 BPM to 82±8 BPM

14 ft: 21% to 13% O2
76±8 BPM to 77±9 BPM

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Conclusions

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- All three prototype devices were within expected HR changes from 21% to 13% O_2
- **Wrist worn device had the closest in range to the PulseOx for HR, but had more losses in connection**
  - Ear and Wrist devices showed significantly more losses in connection upon entering 14 ft.
  - More testing is required to determine if this was due to submersion alone.
- Significant variability in resting HR per individual was noted.

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THANK YOU!

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Funding Sponsor

- USSOCOM/SOF AT&L

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