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ANNUAL TRAINING

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Optimizing Performance in Environmental Extremes: a review and trade-off analysis

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*DISCLAIMER: The views, opinions, and/or findings contained in this presentation are those of the presenters and should not be construed as official Department of the Army or Department of Defense position, view, or opinions.*
Overview

• USARIEM
  – Who are we?
  – What do we do?
• Load Carriage & Performance Background
• Heat & Load Study
• Altitude & Load Study
• Practical Applications
U.S. Army Research Institute of Environmental Medicine
USARIEM conducts biomedical research to improve and sustain Warfighter performance and health under all conditions.

Vision
USARIEM is the internationally recognized joint center of excellence for Warfighter performance and health research.
USARIEM Organization

Biophysics & Biomedical Modeling
- Clothing biophysics
- Biomedical / predictive modeling
- Physiological modeling

Military Performance
- Physical performance optimization
- Injury reduction / bone health
- Muscle physiology
- Military biomechanics research
- Cognitive performance

Military Nutrition
- Bioenergetics and metabolism
- Healthy weight management
- Combat ration testing

Thermal & Mountain Medicine
- Cold & Heat stress physiology
- High altitude physiology
- Environmental illness & injury
- Acquired tolerance & acclimatization
- Hydration

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Doriot Climatic Facility: Largest in North America  
(-57°C to +74°C)  

Thermal Chambers: 
(-10°C to +50°C)
Water Immersion Facility

41 °F  

113 °F
Altitude Research Facilities

Pike’s Peak
(14,110 ft)

Normobaric Hypoxic Room
(16,000 ft)

Hypobaric Chambers
(30,000 ft; -32 to 43° C)
Animal Research Facilities

- AAALAC Accredited Vivarium & Surgical Suite
- Real-Time Physiological, Metabolic & Behavioral Monitoring
- Environmental Controls
- Voluntary & Forced Exercise Models
- Gene Knockout Models
- Rat Models
- Fluid / Tissue Depository
Introduction

• U.S military missions often occur in hot and/or high altitude conditions

• Performance decreases:
  – ↑ Environmental Heat
  – ↑ Altitude
  – ↑ External Load
Performance Background

• Military Loads (Field Manual 21-18):
  – Fighting Load = 48 lbs
  – Approach March Load = 72 lbs
  – Emergency March Load = 120-150 lbs

• Effects of Load:
  – ↑ Metabolic costs (Beekley, 2007)
  – ↑ HR
  – ↑ Ventilatory rate
  – ↑ Oxygen cost
Effects of Load

- Beekley et al. (2007)
- Purpose: examine metabolic responses to 30, 50, & 70% LBM in military personnel during simulated road marching
- 10 male officers:
  - 32 ± 1 years
  - 2 ± 0 meters
  - 80 ± 8 kg

Effects of Load

• March:
  – 30 min 6 km/h
  – Carrying 30, 50, or 70% BW

• Results/ Conclusions:
  – Significantly ↑VO₂, Ventilation, & HR between trials
  – Increasing loads may negatively affect performance
Performance in Heat

Psychological Factors
- Motivation
- Pain Tolerance
- Previous experience of task demand

Respiration
- ↑ respiration
- ↓ PaCO₂
- ↑ pH
- Breathlessness

Cardiovascular Changes
- ↓ stroke volume
- ↓ cardiac output
- ↑ skin perfusion & temp

Peripheral/ Muscular Factors
- Altered/ impaired muscle function
- Impaired oxygen delivery/ perfusion
- Accumulation of metabolites

Neurobiological/ CNS
- Cerebral metabolic changes
- Substrate depletion
- Alterations in regional neurotransmitter levels
- Cerebral / hypothalamus temperature
- Oxygen delivery

Effects of Heat

• Ely et al. (2009)
• Purpose: determine effect of modest hyperthermia on aerobic performance
• 8 non-heat acclimated males:
  – 22 ± 4 years
  – 176 ± 6 cm
  – 75 ± 7 kg

Effects of Heat

• Methods:
  – $\text{VO}_2^{\text{peak}}$ test to determine 50% $\text{VO}_2^{\text{peak}}$
  – Experimental Procedures
    • TEMP = 21°C, 50% RH
    • HOT = 40°C, 25% RH
    • 30 min steady state @ 50%$\text{VO}_2^{\text{peak}}$
    • 15 min time trial
    • Performance measured in total work (kJ) completed in 15 min
Effects of Heat

• Results:
  – Mean performance:
    • TEMP = 177.0 ± 25.0 kJ
    • HOT = 147.7 ± 23.9 kJ
    • Mean decline of 17% (p < 0.05)

• Conclusions:
  – Environmental heat stress can degrade aerobic performance despite modest hyperthermia
Effects of Altitude

- U.S military mission requirements often involve rapid ascent to altitude
- Altitude exposure causes reduced $O_2$ diffusion
- At 2400m, resting $SaO_2$ begins to show a clinically relevant decline (> 4% drop) (Muza et al. 2004)

Effects of Altitude

• Balsom et al. (1994)

• Purpose: To compare high intensity exercise performance during 3000m (hypoxic) and sea level (normoxic) conditions

• 7 Males:
  – 26 ± 1 years
  – 76 ± 3 kg
  – 4 ± 0 L·min⁻¹

Effects of Altitude

• Methods:
  – 10 bouts (6 sec) high intensity exercise
    • Altitude: Hypoxic conditions (526 mmHg; 3000 m)
    • Sea level: Normoxic conditions
  – Performance Measures:
    • Pedaling frequency & oxygen uptake
Effects of Altitude

• Results:
  – Peak O₂ uptake was ~15% lower in hypoxic (3.74 ± 0.2) vs normoxic conditions (4.45 ± 0.2) (p < 0.05)
  – After 8 bouts, pedaling speed was lower in hypoxia condition (p < 0.05)

• Conclusions:
  – Ability to maintain high power output is impaired by hypobaric hypoxia at 3000m
  – Hypoxia is shown to impact repeated sprint performance
Performance Questions

• What’s the direct impact of heat on load carriage?

• What’s the direct impact of altitude on load carriage?

• Goal: Trade-off Analysis/Guidance
Heat & Load

• 5 Mar 2013, CPT Raj, physician deployed in Afghanistan, made a RFI on the effect of heat and load on performance in a deployed environment.

• *Purpose:* To determine the impact external loads in temperate (20 C) and hot (40 C) environments on aerobic exercise performance.

• *Hypotheses:* Greater external loads combined with high environmental heat stress, will have a greater detrimental impact on performance than in temperate environments.

• *End Goal:* Develop decision aids (matrix) for trade-off analyses of impact of load on aerobic performance capabilities in temperate and hot environments.
What’s the maximum equipment load for our mission?
Heat & Load

• Design & Methodology

<table>
<thead>
<tr>
<th>BAPL 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>20% Body Mass</td>
</tr>
<tr>
<td>20°C</td>
</tr>
<tr>
<td>30% Body Mass</td>
</tr>
<tr>
<td>20°C</td>
</tr>
<tr>
<td>50% Body Mass</td>
</tr>
<tr>
<td>20°C</td>
</tr>
</tbody>
</table>

• Primary outcome variable: 5km time trial
Heat & Load

• 5km Familiarization
  – 3 Trials
  – ACH, Weapon, PT’s, Sneakers

• Speed & Time Blinded
  – Only feedback: distance reached
Altitude & Load

• **Purpose:** Study the degradation of aerobic performance by high-altitude. The impact of high-altitude on recovery during repeated anaerobic tasks is unknown and will also be studied.

• **Hypotheses:**
  – 1. Progressively higher altitudes vs. sea-level reduction will have a greater negative impact on mission performance.
  – 2. The number of repeated 30 second sprints bouts until peak velocity is less than 50% of sea level peak velocity will be fewer at 2000 and 3000m.

• **End-goals:**
  – Develop decision aid (model and/or graphics) of the impact of load on aerobic and anaerobic performance at high altitude.
  – Develop trade-off analyses (matrix) on impact of load on aerobic and anaerobic exercise performance capabilities at sea level and high-altitude environments. (in progress)
# Altitude & Load

## Design & Methodology

### Aerobic (5K) Testing Group

<table>
<thead>
<tr>
<th>Group</th>
<th>Load (% body mass)</th>
<th>Altitude (meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>n = 9 (6 males, 3 females)</td>
<td>30%</td>
<td>250 m (SL)</td>
</tr>
<tr>
<td></td>
<td>*Total skin-out load</td>
<td>2000 m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5 km time trial</td>
</tr>
</tbody>
</table>

### Anaerobic (Sprint) Testing Group

<table>
<thead>
<tr>
<th>Group</th>
<th>Load</th>
<th>Altitude (meters)</th>
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</thead>
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<tr>
<td></td>
<td>*Total skin-out load</td>
<td>2000 m</td>
</tr>
<tr>
<td></td>
<td>Repeated sprints</td>
<td>Repeated sprints</td>
</tr>
</tbody>
</table>
Study Design

- PTs
- Sneakers
- Helmet
- Carrying a weapon
5K Familiarization

• Three practice sessions
  – 5K time trial @ sea level
  – Reduce intra-subject variability and treadmill “learning curve” (Tyler & Sunderland, 2008)

Sprint Familiarization Testing

• Three practice sessions
  – 30 sec all-out sprint: 60 sec rest
  – Reduce intra-subject variability and treadmill “learning curve” (Tyler & Sunderland, 2008)

• Establish End point: peak velocity decreased by 20% of peak velocity established in familiarization

Study Design

**Phase**
- **Familiarization**
- **Experimental**

**Week**
- Week 1
- Week 2
- Week 3
- Week 4
- Week 5

- **ACU trousers**
- **Sneakers**
- **Body Armor**
- **Helmet**
- **Carrying a weapon**
- **Pack**

- 250m (SL)
- 2000m
- 3000m

- **30% body weight**

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Measurements

- HR recorded during all exercise testing
- Duration of time recorded throughout 5K time trials
- SaO₂, RPE, and number of sprints completed recorded during sprint exercise testing
Conclusions

**5K**

- Time trial duration increased at 3000m when compared to SL
  - Duration did not increase at 2000m when compared to SL

**Sprint**

- Repeated sprint performance was not affected by hypobaric hypoxia

- Reduced SaO₂ values did not alter the aerobic recovery of anaerobic pathways used during sprinting
  - SaO₂ values observed did not decrease enough to be a limiting factor
Future Research

5K

• Perform 5k time trials with varying loaded weight
  – 0%, 30%, 50% of respective body weight

Sprint

• Perfect the methodology of sprint sessions to decrease inter-subject variability.

Overall

• Further decreasing the barometric pressure tested could produce an increase in time trial duration and a decrement in the number of completed sprints.
Practical Applications

• Mission Dependent

• Best Preparations:
  – Train
  – Loaded
  – Acclimatization
    • Acetazolamide?
Practical Applications-Heat

- Acclimation
- Clothing
- Load
- Hydration
- Nutrition
Practical Applications-Altitude

- Acclimatization
  - Acetazolamide?
- Load
- Hydration
- Nutrition
- Experience

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