State of the Science of Military Human Performance Optimization

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State of the Science Symposia Series: Fitness and Health Outcomes: Exercise, Health, and Nutrition for Wounded, Injured and Ill Veterans
Wednesday, 30 March 2016
Warrior Human Performance Research Center

Culture of Academic and Research Excellence

University of Pittsburgh

Top 50 Research University in World
(2105 US News and World Report Rankings)

Top 100 Best Global University
(2015-16 Times Higher Education World University Rankings)

Top 5 among US medical schools in NIH funding

Neuromuscular Research Laboratory/ 
Warrior Human Performance Research Center

Musculoskeletal Injury Prevention and Human Performance Optimization

Neuromuscular Research Laboratory
Established in 1987 to describe effects of injury on joint proprioception, neuromuscular control, and functional joint stability

Warrior Human Performance Research Center
Military emphasis started in 2005 as musculoskeletal injuries represent a threat to military readiness and national security
“The more you sweat in peace the less you bleed in war.”

Sun Tzu
Chinese Military Strategist
~500 BC
“Our national security in the year 2030 is absolutely dependent upon what is going on in pre-kindergarten today.”

-Rear Admiral James Barnett, US navy (Ret.)

Too Fat to Fight
Retired Military Leaders Want Junk Food Out of America’s Schools

A Report by

MISSION: READINESS
MILITARY LEADERS FOR KIDS

Still Too Fat to Fight

We cannot succeed in teaching our children to eat healthier foods while selling them 400 billion junk food calories in our schools every year.

A Follow-up Report to Too Fat to Fight

MISSION: READINESS
MILITARY LEADERS FOR KIDS
The Army will deploy smaller formations that have to be tailorable, scalable and more expeditionary.

Professional Soldier Athlete: The Cornerstone of Strategic Landpower’s Human Dimension

Deydre S. Teyhen
Relevance of Military Physical Readiness to National Security

“Environmental Scanning”

• Military “drawdown” 570K to <450K
  – Fewer Soldiers to accomplish mission
  – Budget constraints ($31 billion cut in ’14, $45 billion cut ’15)
• Musculoskeletal Injuries (MSI) continue to degrade readiness
  – 15-30% of Soldiers considered MNR to deploy ($6B in salary)
  – VA MSI disability payments = $5.5B/$21B total
• Load Carriage
  – Soldiers are expected to carry heaviest loads in history
• Expanded Role For Women in Military
  – Women 2-3 times more likely to be injured than men
• Changing Army Fitness Policies and Landscape
  – Military Physical Fitness Test Procedures
  – Emerging Commercial Programs; Unit-based training programs

Essential to Employ Optimal, Evidence-Based Physical Readiness Programs
HEALTH OF THE FORCE

Create a healthier force for tomorrow.

NOVEMBER 2015

Percent of AD Soldiers Meeting National Goals and Standards for Sleep

55% did not meet targets
30% met some targets
15% met all targets

**Adapted from System for Health Playbook, OTSG July 2015
† Based on a cross-section of GAT surveys completed by AD Soldiers in 2014 (n=175,619)

Percent of AD Soldiers Meeting National Goals and Standards for Activity

34% did not meet targets
28% met some targets
38% met all targets

**Adapted from System for Health Playbook, OTSG July 2015
† Based on a cross-section of GAT surveys completed by AD Soldiers in 2014 (n=175,619)

Percent of AD Soldiers Meeting National Goals and Standards for Nutrition

34% did not meet targets
29% met some targets
13% met all targets

**Adapted from System for Health Playbook, OTSG July 2015
† Based on a cross-section of GAT surveys completed by AD Soldiers in 2014 (n=175,619)
Strategies for Optimizing Military Physical Performance

GAPS:
1: Absence of adequate data to quantify effectiveness. (Rand Study, 2013)
2: Poor synchronization, integration, and communication of HPO/IP efforts across military commands and operators, health practitioners, researchers and leaders
Human Dimension Proof of Concept

Athletic Performance Portfolio Prioritization

10-11 Feb 2016; TRAC-WSMR HD Division

• Key Task: Leverage the most advanced techniques in health, sports medicine, nutrition, and fitness to increase wellness and optimize the physical performance of our Soldiers and Army Civilians

• Physical Readiness Definition: The ability to meet the physical demands of any combat or duty position, accomplish the mission, and continue to win.
  – Physical Dominance
    • Overmatch
    • Strength
    • Agility
    • Speed
    • Endurance
Human Dimension Proof of Concept
Athletic Performance Portfolio Prioritization
10-11 Feb 2016; TRAC-WSMR HD Division

• Evaluation Criteria
  – Relevance
  – Scalability
  – Ease of Implementation
  – Effectiveness
  – Assessment Plan
  – Potential Cost Avoidance
  – Efficiency
Evaluation Criteria

– Relevance (27)
– Scalability (12)
– Ease of Implementation (15)
– Effectiveness (25)
– Assessment Plan (8)
– Potential Cost Avoidance (7)
– Efficiency (6)
Human Dimension Proof of Concept
Athletic Performance Portfolio Prioritization
10-11 Feb 2016; TRAC-WSMR HD Division

- Army MFTC; U.S. Army Physical Fitness School
- Army Wellness Centers Program; MEDCOM
- Brigade Physical Therapy; MEDCOM
- CSF2; HQDA; G-1
  - Global Assessment Tool (GAT)
  - ArmyFit
- Army Move; MEDCOM
- Forward Musculoskeletal Care; MEDCOM
- I-PREP; Center for Initial Military Training
- MWR Fitness Centers; OACSIM
- PR-Bar; Maneuever Center of Excellence
- Performance Triad, OTSG
- P3T; MEDCOM
- THOR3; USASOC
DoD Human Performance Optimization Committee (HPOC) Meeting; 4 Feb 2016

- Policy WG
  - Chair – Dr. Cara Krulewitch, OASD(HA)

- Warrior Readiness/Fit to Perform WG
  - Chair – Dr. Travis Harvey (HQ SOCOM)

- Women in Combat WG
  - Chair – Maj. Angela Yarnell (Center for Military Psychiatry and Neuroscience Research, Walter Reed Army Institute of Research)
  - Iron Deficiency Subgroup co-chairs (invited) – Dr. James McClung (USUHS) and Dr. Patty Deuster (USUHS)

- Solutions WG
  - Co-chairs (notional) – BG Sean Murphy (USAF Air Combat Command) and BG John George (USA Capabilities Developments Directorate)

- Total Force Fitness Capability Based Assessment; CAPT Kimberly Elenberg, Defense Health Agency
Scope and Impact of Musculoskeletal Injuries on Military Readiness

- 2.2 million MSI-related medical encounters impacting 600K service members

- Injury incidence rates
  - Basic Combat Training: 19%-40% Men; 40%-67% Women
  - Advanced Individual Training: 24%-40% Men; 30%-60% Women
  - Operational Units (Infantry, Armor, Military Police): 5%-13% per month
  - Physical Training and Sports are Leading causes
    - Ordnance: 53%-63%
    - Armor: 40%
    - Garrison: 38%
    - Infantry: 58%
    - Army War College Students: 42%
What does the Scientific Literature Report for the Relationship between Running Mileage, Performance and Injury Rates?

• Lower running volumes results in similar performance times, yet fewer injuries!
  – **Marine Study**: 33 miles vs. 55 miles over 12 weeks. ➔ Lower stress fractures and similar run times. Shaffer, 1996.
What does the Scientific Literature Report for the Relationship between Running Mileage, Performance and Injury Rates?

One of the most significant control measures to reduce MSIs is to limit long distance running.
Musculoskeletal Injuries Negatively Impact Deployability and Military Readiness

Medical Evacuations from GWOT

- Musculoskeletal Injury: 24%
- Combat Injury: 14%

Cohen, Lancet, 2010
Physiological Employment Standards III: physiological challenges and consequences encountered during international military deployments  EJAP, 2013

Bradley C. Nindl · John W. Castellani · Bradley J. Warr · Marilyn A. Sharp · Paul C. Henning · Barry A. Spiering · Dennis E. Scofield
## Physiological Responses to Deployment

### Summary of Changes Across all 4 studies

<table>
<thead>
<tr>
<th>Category</th>
<th>Changes Reported</th>
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<tbody>
<tr>
<td><strong>Aerobic Capacity</strong></td>
<td>3 decrease; 1 no change</td>
</tr>
<tr>
<td><strong>Strength, Power and Endurance</strong></td>
<td>2 decrease; 14 increase or no change</td>
</tr>
<tr>
<td><strong>Body Composition</strong></td>
<td></td>
</tr>
<tr>
<td>Body Mass</td>
<td>3 decrease; 1 increase</td>
</tr>
<tr>
<td>Fat Mass</td>
<td>2 decrease; 2 increase</td>
</tr>
<tr>
<td>Fat-free mass</td>
<td>1 decrease; 1 increase</td>
</tr>
</tbody>
</table>

### Consistent findings

- **Aerobic Capacity**
- **Muscle Strength, Power, Endurance**
Physical Readiness Training

- Standardized Physical Readiness Training (SPT) group (n=1284) vs. Control (n=1296).

- Compared to SPT, the relative risk of a time-loss overuse injury for the control group was 1.5 for men and 1.4 for women.

- For the final APFT, the SPT group had a higher pass rate (85% vs. 81% for men and 80% vs. 70% for women).

**CONCLUSION:** Standardized Physical Readiness Training is more effective and safer than traditional training.

**RESULT:** Army-wide implementation.

Rate Per 1,000 PY

Calendar Year


Implementation of standardized PT

- All injuries
- Lower extremity overuse injuries
Lingering Questions

- What specifically makes the standardized physical training program superior?

- Is the Army Physical Fitness Test the most valid measure of “combat-readiness”?

- Is the standardized physical reading training optimal for elite and highly fit Warfighters?

- Are we really training how we fight?
Similar metabolic adaptations during exercise after low volume sprint training and traditional endurance training


- 6 weeks of training
  - Endurance training (4.5 hr/week)
    • 40-60 min of cycling @ 65% VO2 max, 5X/week
  - Sprint interval training (1.5 hr/week)
    • 4-6 repeats of Wingate tests, separated by 4.5 min recovery, 3X/week

• Results: similar improvements in mitochondrial markers for skeletal muscle CHO and lipid oxidation

• These results suggest that high-intensity interval training is a time-efficient strategy to increase skeletal muscle oxidative capacity and induce specific metabolic adaptations during exercise that are comparable to traditional endurance training.
Paavo Nurmi

“I don’t run naked”
“Soldiers don’t go into combat with t-shirts and shorts”
Soldier Loads Through History

Knapik Mil Med 2004

Load Carried (lbs)

Civil War | WW I | WW II | Vietnam | Desert Shield | Desert Storm | OEF/OIF

0 | 10 | 20 | 30 | 40 | 50 | 60 | 70
Operational Physical Performance and Fitness in Military Women: Physiological, Musculoskeletal Injury, and Optimized Physical Training Considerations for Successfully Integrating Women Into Combat-Centric Military Occupations

Bradley C. Nindl, PhD*; Bruce H. Jones, MD, MPH*; Stephanie J. Van Arsdale, MS†; Karen Kelly, PhD‡; William J. Kraemer, PhD§
Augmenting Women’s Military Physical Performance

Effect of resistance training on women’s strength/power and occupational performances
Kraemer et. al., MSSE 2001

Changes in Muscle Hypertrophy in Women with Periodized Resistance Training
Kraemer et. al., MSSE 2004

A Few Good Women
15 March 2015
for Male and Female Soldiers

Incremental Dynamic Lifting Strength (kg)

Overlap between strongest women and weakest men

from M.A. Sharp
Lower and Upper Body Power Changes
Pre to Post 6 Months of Training

% Change in Power Output

Lower-Body
Upper-Body

Pre
Post
Upper Arm

TP
UP
TH
UH
Con

* Indicates significant change
Changes in Load Carriage Time
Pre to Post 6 Months of Training

![Graph showing changes in 2m Load Run (s) between Pre and Post for different groups (TP, TS, UP, UH, F, A). The graph includes error bars indicating variability. Significant differences are marked with an asterisk (*) for each group.](chart.png)
1-RM Squat
1-RM Bench Press
1-RM High Pull
1-RM Box lift
Sit-Ups
2m Load Run
Repetitive Box Lift
Push-Ups
Squat Endurance

% of Men
Squat Endurance
2m Run
Push-Ups
2m Load Run
Repetitive Box Lift
Sit-Ups
1-RM Box lift
1-RM High Pull
1-RM Bench Press
1-RM Squat

% of Men

Most Militarily Relevant
Maximal Strength
Physical Training Strategies for Military Women’s Performance Optimization in Combat-Centric Occupations

Bradley C. Nindl  JSCR, 2015

**Female soldiers** (vs. Male soldiers):
- Higher musculoskeletal injury rates
- Less upper-body strength
- Capable of achieving similar relative gains following occupationally-relevant training

**Selection:** Women with highest potential for physical capacity

- Development/application of occupational task standards
- Innovative doctrine that operationalizes best practices
- Flexible nonlinear periodized training programs
- Low-volume, high-intensity interval training
- Heavy resistance (3-8 RM range) to maximize strength/power
- Greater emphasis on upper body strength/power development
- Incorporation of progressive load carriage training
- Minimum of 6 months of combined resistance/endurance training

**Optimized gender integration into combat-centric MOS roles**
# Executive Summary from the National Strength and Conditioning Association’s Second Blue Ribbon Panel on Military Physical Readiness: Military Physical Performance Testing

**Bradley C. Nindl,**¹,² **Brent A. Alvar,**³ **Jason R. Dudley,**⁴ **Mike W. Favre,**⁵ **Gerard J. Martin,**⁶ **Marilyn A. Sharp,**⁷ **Brad J. Warr,**⁷ **Mark D. Stephenson,**⁸ and **William J. Kraemer⁹**

> Table 3. SME ratings for the degree to which health- and skill-related fitness components were required to accomplish common military tasks.*†‡

<table>
<thead>
<tr>
<th>Military tasks</th>
<th>Strength</th>
<th>Power</th>
<th>Endurance</th>
<th>Body composition</th>
<th>Coordination</th>
<th>Balance</th>
<th>Agility</th>
<th>Flexibility</th>
<th>Aerobic fitness</th>
<th>Speed</th>
<th>Reaction time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jump or leap over obstacles</td>
<td><strong>7.5</strong></td>
<td><strong>9.0</strong></td>
<td>4.0</td>
<td>6.4</td>
<td>6.9</td>
<td>5.7</td>
<td>6.5</td>
<td>5.9</td>
<td>2.6</td>
<td>5.7</td>
<td>4.0</td>
</tr>
<tr>
<td>Move with agility-coordination</td>
<td>4.7</td>
<td>5.4</td>
<td>5.5</td>
<td>5.8</td>
<td><strong>9.5</strong></td>
<td><strong>8.4</strong></td>
<td><strong>9.8</strong></td>
<td>6.1</td>
<td>4.1</td>
<td>6.5</td>
<td>6.6</td>
</tr>
<tr>
<td>Carry heavy loads</td>
<td><strong>8.8</strong></td>
<td>6.2</td>
<td>7.5</td>
<td>5.2</td>
<td>3.7</td>
<td>5.0</td>
<td>2.9</td>
<td>3.3</td>
<td>5.5</td>
<td>2.2</td>
<td>1.6</td>
</tr>
<tr>
<td>Drag heavy loads</td>
<td><strong>9.2</strong></td>
<td><strong>7.4</strong></td>
<td>7.4</td>
<td>5.2</td>
<td>4.5</td>
<td>4.8</td>
<td>3.3</td>
<td>3.8</td>
<td>5.2</td>
<td>2.7</td>
<td>1.6</td>
</tr>
<tr>
<td>Run long distances</td>
<td>3.8</td>
<td>3.1</td>
<td>6.9</td>
<td>5.2</td>
<td>3.2</td>
<td>3.2</td>
<td>3.0</td>
<td>3.2</td>
<td><strong>9.9</strong></td>
<td>9.9</td>
<td>1.4</td>
</tr>
<tr>
<td>Move quickly for short distances</td>
<td>6.0</td>
<td><strong>7.8</strong></td>
<td>6.4</td>
<td>6.2</td>
<td>7.0</td>
<td>6.4</td>
<td><strong>7.8</strong></td>
<td>4.4</td>
<td>4.0</td>
<td>9.3</td>
<td>6.0</td>
</tr>
<tr>
<td>Climb over obstacles</td>
<td><strong>8.3</strong></td>
<td>6.5</td>
<td>5.7</td>
<td>6.7</td>
<td>7.0</td>
<td>6.1</td>
<td>6.0</td>
<td>5.9</td>
<td>3.9</td>
<td>4.1</td>
<td>2.2</td>
</tr>
<tr>
<td>Lift heavy objects off ground</td>
<td><strong>9.7</strong></td>
<td><strong>7.7</strong></td>
<td>5.4</td>
<td>5.5</td>
<td>4.8</td>
<td>5.1</td>
<td>2.7</td>
<td>5.0</td>
<td>3.0</td>
<td>2.3</td>
<td>1.6</td>
</tr>
<tr>
<td>Load/stow/mount hardware</td>
<td><strong>7.7</strong></td>
<td>6.0</td>
<td>6.3</td>
<td>5.0</td>
<td>5.7</td>
<td>5.3</td>
<td>3.4</td>
<td>4.9</td>
<td>3.6</td>
<td>2.6</td>
<td>2.2</td>
</tr>
<tr>
<td>Overall mean</td>
<td><strong>7.3</strong></td>
<td>6.6</td>
<td>6.0</td>
<td>5.9</td>
<td>5.8</td>
<td>5.5</td>
<td>5.0</td>
<td>4.7</td>
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<td>4.4</td>
<td>3.0</td>
</tr>
</tbody>
</table>

*SME = subject matter expert.
†A scale from 1 to 10 was used to rate how much each health- or skill-related fitness component contributed to completing military tasks.
‡Bold values are those rated by SMEs as >7.0 for essential capacity needed to accomplish the task.
## Systematic Review of the Effects of Physical Training Load on Load Carriage Performance

(Knapik et al., JSCR 2012)

### Training Modalities and Combinations:

- **Aerobic Training**
- **Upper Body Resistance Training**
- **Lower Body Resistance Training**
- **Load Carriage Exercise**
- **Field-Based Training**

### Training Load Carriage Parameters

<table>
<thead>
<tr>
<th>Study</th>
<th>Distance</th>
<th>Load</th>
<th>Duration/Frequency</th>
<th>Quality Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knapik and Gerber (1996)</td>
<td>5 km; 19 kg</td>
<td>14 wks; 5X/wk</td>
<td>80±4</td>
<td></td>
</tr>
<tr>
<td>Harman et al. (1997)</td>
<td>3.2 km; 34 kg</td>
<td>24 wks; 5X/wk</td>
<td>80±5</td>
<td></td>
</tr>
<tr>
<td>Williams et al. (1999)</td>
<td>3.2 km; 25 kg</td>
<td>11 wk; not defined</td>
<td>78±5</td>
<td></td>
</tr>
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<td>Williams et al. (2002)</td>
<td>3.2 km; 25 kg</td>
<td>11 wk; not defined</td>
<td>78±5</td>
<td></td>
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<tr>
<td>Harman et al. (2008)</td>
<td>3.2 km; 32 kg</td>
<td>8 wks; 5X/wk</td>
<td>78±5</td>
<td></td>
</tr>
<tr>
<td>Kraemer et al. (2004)</td>
<td>3.2 km; 45 kg</td>
<td>12 wks; 4X/wk</td>
<td>76±5</td>
<td></td>
</tr>
<tr>
<td>Hendrickson et al. (2010)</td>
<td>3.2 km; 33 kg</td>
<td>8 wks; 3X/wk</td>
<td>76±5</td>
<td></td>
</tr>
<tr>
<td>Knapik et al. (1990)</td>
<td>20 km; 46 kg</td>
<td>9 wks; 4-5X/wk</td>
<td>74±5</td>
<td></td>
</tr>
<tr>
<td>Brown et al. (2008)</td>
<td>2.4 km; 20 kg</td>
<td>21 wks, not defined</td>
<td>66±6</td>
<td></td>
</tr>
<tr>
<td>Kraemer et al. (2001)</td>
<td>3.2 km; 34 kg</td>
<td>24 wks; 3X/wk</td>
<td>60±2</td>
<td></td>
</tr>
<tr>
<td>Training Mode</td>
<td>Summary Effect Size (summary 95%CI)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------------------------------------------------------------------------</td>
<td>-------------------------------------</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Upper &amp; Lower Body resistance training with aerobic training and load carriage exercise</td>
<td>1.69 (1.04 – 2.32)</td>
<td></td>
<td></td>
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<tr>
<td>Periodized Upper and Lower Body resistance training with aerobic training</td>
<td>1.18 (0.69-1.67)</td>
<td></td>
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<tr>
<td>Field based training with load carriage exercise</td>
<td>1.11 (0.77-1.45)</td>
<td></td>
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<td>Linear Upper and Lower Body resistance training with aerobic training</td>
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<td>Upper body resistance training with aerobic training</td>
<td>0.79 (0.16-1.42)</td>
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<td>Upper and Lower Body resistance training only</td>
<td>0.75 (-0.14-1.64)</td>
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# Meta Analysis Summary

## Training Modes and Combinations

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## Meta Analysis Summary

### Training Modes and Combinations

<table>
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<th>Training Mode</th>
<th>Summary Effect Size (summary 95%CI)</th>
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Combined resistance and endurance training improves physical capacity and performance on tactical occupational tasks

Combined training showed the largest percent improvement in tactical occupational performances.

EJAP, 2010
PERSPECTIVES ON AEROBIC AND STRENGTH INFLUENCES ON MILITARY PHYSICAL READINESS: REPORT OF AN INTERNATIONAL MILITARY PHYSIOLOGY ROUNDTABLE

KARL E. FRIEDL, 1 JOSEPH J. KNAPIK, 1, 2 KEIJO HÄKKINEN, 3 NEAL BAUMGARTNER, 4 HERBERT GROELLER, 5 NIGEL A.S. TAYLOR, 5 ANTONIO F.A. DUARTE, 6, 7 HEIKKI KYRÖLÄINEN, 3 BRUCE H. JONES, 8 WILLIAM J. KRAEMER, 9 AND BRADLEY C. NINDL 2, 10

3rd International Congress on Soldiers’ Physical Performance
Warfighter Readiness Roundtable
Explosive-strength training improves 5-km running time by improving running economy and muscle power

• Endurance trained athletes underwent strength/power training; equated for training volume
  – Plyometrics, low load, high velocity
  – Experimental (32%)
  – Control (3%)

• Greater improvements in:
  – 5K run time
  – Running economy
  – 20 m sprint
  – Anaerobic capacity
  – 5 jump performance

• Physiological Basis: neuromuscular
• Military relevance

Paavolainen et al., JAP, 1999
Bone Health Research

**Threat:** Stress Fracture Incidence Rate (4-20%)

**Biomedical Research Solution:** Novel Imaging Analysis

STUDIES
- UConn.: Exercise (Control, Aerobic, Resistance, Combined)
- Karakal (IDF): IDF Basic training (Control, Basic) Primarily female
- Shaldag (IDF): IDF Basic training (Control, Basic) All male
- Great Lakes NTC: Vitamin D suppl.
• Not all exercises are equally effective
• Prolonged exercise has diminishing returns
• New measure of effectiveness for exercise protocols: Osteogenic index ("OI") = intensity × ln (N+1)
• Ample and convincing evidence in animals models
• Is the “OI” valid in an exercising human model?
Mechanical Parameters Affecting Bone Adaptation

- Dynamic vs. Static Mechanical Loading (Hert)

Double fluorochrome labeling of ulnar diaphysis

Osteogenic potency of dynamic loading on periosteal and endocortical surfaces.

Robling et al. Bone, 2001
Mechanical Parameters Affecting Bone Adaptation

- Dynamic vs. Static Mechanical Loading (Hert)
  - Hydrostatic pressure gradients within bone’s fluid-filled canalicular network.
  - Shear stresses are created on plasma membranes of osteocytes and osteoblasts.
  - Cascade of cellular events (increased calcium, paracrine/autocrine secretion of growth factors, bone matrix formation)

![Diagram showing IM Pressure and Bone Formation](image)

**Fig. Total new bone formation response to fluid flow loading.**
Prolonged Exercise Has Diminishing Returns

- **Mechanostat**: Bone cells exhibit a desensitization phenomenon in the presence of extended mechanical-loading sessions.

Anabolic response to loading appears saturated after 40 loading cycles.
Bone tissue desensitizes to mechanical loading rapidly. As loading cycles (N) increase, the mechanosensitivity decreases as $1/(N+1)$.

Consequently, exercise is most effective if delivered in short bouts separated by several hours.

After loading is stopped, the mechanosensitivity recovers, where $\tau$ approximately 6 h.
Exercise Applications

What is the most effective manner to apply mechanical forces to promote osteogensis?

- High-impact exercises that produce large rates of deformation of the bone matrix best drive fluid flow through the lacunar-canicular network system.

Are exercise programs designed to improve muscle and aerobic fitness the best for also improving bone health?
Influence of exercise mode and osteogenic index on bone biomarker responses during short-term physical training \textit{Bone, 2009}

Mark E. Lester \textsuperscript{a}, Maria L. Urso \textsuperscript{a}, Rachel K. Evans \textsuperscript{a}, Joseph R. Pierce \textsuperscript{a}, Barry A. Spiering \textsuperscript{b}, Carl M. Maresh \textsuperscript{b}, Disa L. Hatfield \textsuperscript{b}, William J. Kraemer \textsuperscript{b}, Bradley C. Nindl \textsuperscript{a,*}
pQCT (quantitative computed tomography) Overview

- Measures true volumetric density (mg/cm³) unlike DXA
- Can assess trabecular and cortical bone separately
- Radiation exposure
  - 0.3 – 1.5 μSv per scan (Braun, 1998)
  - 5-10x lower than typical daily exposure
  - 50 mSv/year (~137 μSv/day) Federal exposure limit for radiation workers
  - 24 μSv per scan with conventional CT
- Extensively validated
  - Precision
  - Accuracy
TrDn increased at 4% in exercise groups at the medial-posterior site. This may be the earliest manifestation of bone adaptation.
Estimating Osteogenic Index (OI)

Osteogenic Potential (index) = intensity $\times \ln (N+ 1)$
Recovery (%) = intensity $\times \ln (N+ 1) \times 1-e^{-t/\tau}$

2X/day group experienced **44% greater OI** than 1X/day group.

**2X/day** group increased **31%** pre-to post-training in 1 RM leg strength compared to **21%** in the 1X/day group.
38% CtDn 2X/day

Unpublished data
Summary

• Evidence for use of the “OI” in an animal model is compelling and well-established.

• The available evidence for use of the “OI” in a human model appears provocative, but not yet definitive.

• High-resolution imaging technologies (pQCT, MRI) to include “regional analyses” programs are essential to detect subtle changes (i.e. medial-posterior) that may have been difficult to detect with conventional measures (DXA).

• Development of novel exercise programs that consider the bone’s “mechanostat” (i.e. dynamic loading and rest/recovery periods) are encouraged and should be a point of emphasis for future research.
  – Power vs. Strength (Stengel et al., JAP, 2005)
Human Performance Optimization (HPO) and Injury Prevention (IP): Essential for Military Readiness and National Security

**HPO/IP Threats to National Security**
- Epidemic of musculoskeletal Injuries
- Decreased fitness and increased obesity
- Increasing and excessive external loads
- Physically demanding occupations
- High operational tempo
- Non-deployable status of personnel
- Veteran Health and Wellness

“*The more you sweat in peace the less you bleed in war.*”
Sun Tzu, Chinese Military Strategist
~500 BC

**Increased Senior Leader Military Prioritization**
- Tactical Human Optimization, Rapid Rehabilitation and Reconditioning

**Biomedical Research Solutions**
- State-of-the-Science Best Practices
- Performance Optimization programs
- Injury Prevention Programs
- Return-to-duty guidelines
- Personalized medicine
- Evidence-based medicine
- Systems Biology
- Innovative technologies

- 30 yr history of Sports Medicine Research
- 10 yr history of DoD HPO/IP Research
- Leadership has over 55 yrs of military experience
- Unique understanding of DoD HPO/IP gaps
- Multi-disciplinary, team-centric approach
- Cutting-edge and innovative research capabilities
- International Partnerships