University of Pittsburgh

The 33rd Finnish Exercise Testing Symposium, Helsinki Finland,March 29-30, 2023

Physiological Monitoring of Resilience During Arduous Tactical Training: Maintaining Readiness and Occupational Performance

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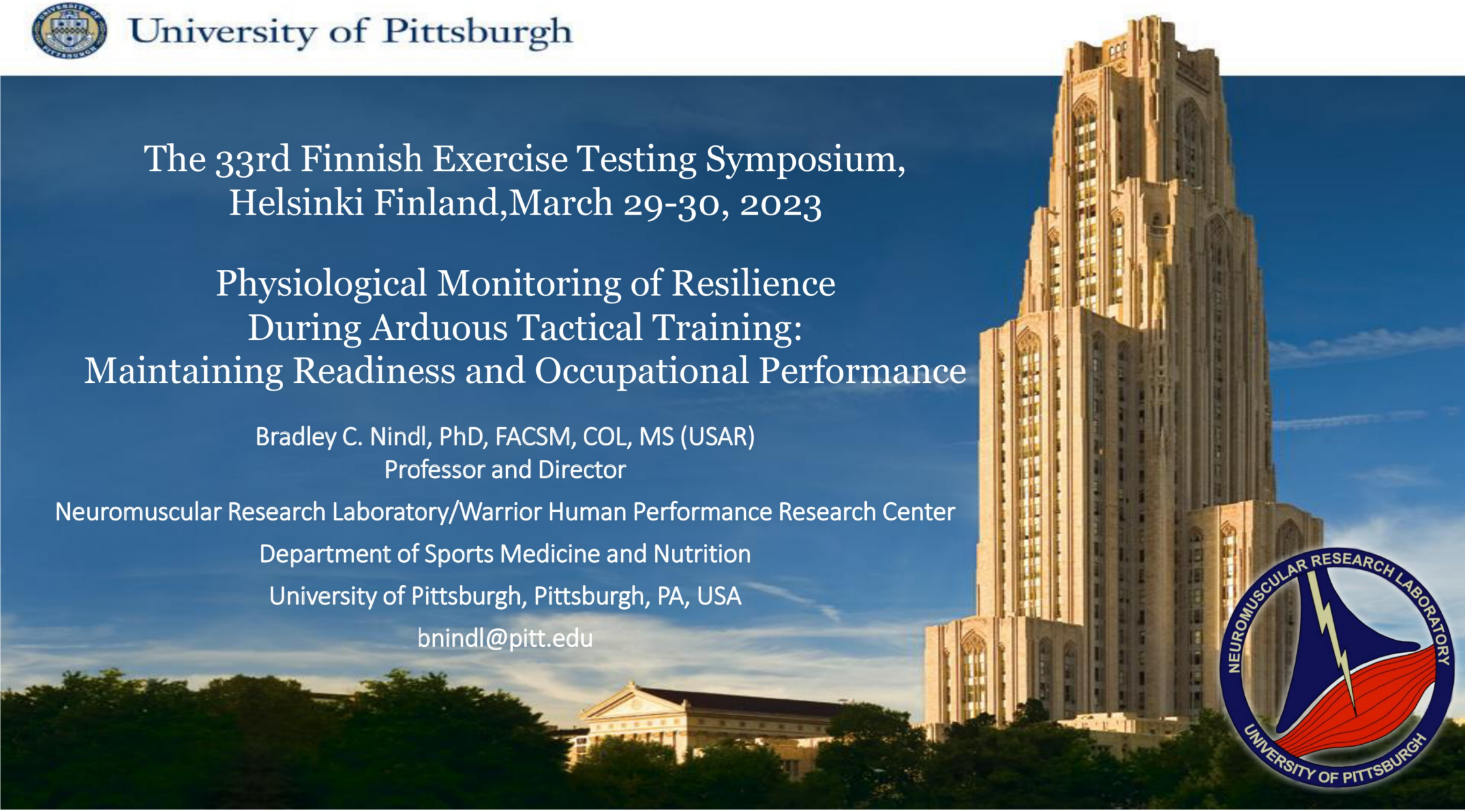


University of Pittsburgh

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

School of Health and Rehabilitation Sciences

#1 for Health Professions
(2015 USA Today Rankings)

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

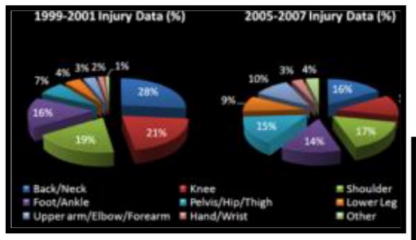
Eagle Tactical Athlete Program (ETAP)

University of Pittsburgh / The US Army 101st Airborne Division (Air Assault)

THREATS TO THE FORCES: "Musculoskeletal Injuries in the Military: A Hidden Epidemic"

SOLUTIONS: Systematic and Scientific Approach (Public Health Model) for Injury Prevention and Performance Optimization

Phase I: Injury Surveillance and Task/Demand Analysis



- Development of customized database for medical information and laboratory data

- Field assessments of military tasks and energy requirements during tactical training

Phase II: Predictors of Injury and Optimal Performance

- Laboratory tests to replicate biomechanical tasks and physiological demands and performance measures
- Over 1000 testing sessions completed

Phase III: Development / Validation of ETAP

- Based on the non-linear periodization model
- Clinical Trials to validate the effectiveness of the predictors of injury and optimal performance

Phase IV: ETAP Division Implementation and Monitoring

- Develop a 4-day school and validate knowledge transfer
- Implementation of ETAP Division-wide (~25,000 Soldiers)
- ETAP resulted in significant reductions in the proportion of soldiers with musculoskeletal injuries

Remote Neuromuscular Research Laboratory Capability

Complete Assessment and Measurement of Human Physical Performance

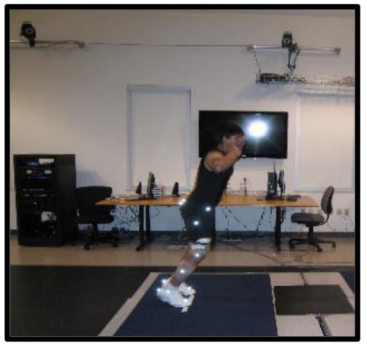
Physiological Assessment

Treadmill w/metabolic cart
Aerobic Capacity

Velotron ergometer
Anaerobic Performance

Bod Pod
Body Composition

Motion Analysis

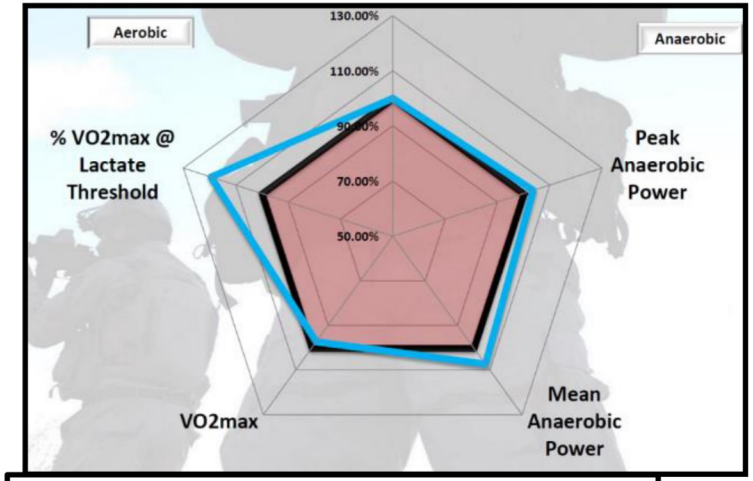


Vicon Motion Analysis
Biomechanical Assessment

Neuromuscular Assessment

Biodex
Muscular Strength

Neurocom
Sensorimotor Control



Individualized Health Performance Readiness Report

Monitoring work and training load in military settings – what's in the toolbox?

Scott W. Michael [a], Andrew G. Siddall [b], Thomas J. O'Leary[c], Herbert Groeller [a], John A. Sampson [a], Sam D. Blacker [b] and Jace R. Drain [d]

JSAMS 2022

[a]Centre of Medical and Exercise Physiology, University of Wollongong, Wollongong, Australia; [b]Occupational Performance Research Group, Institute of Sport, University of Chichester, Chichester, UK; [c]Army Health and Performance Research, Army Headquarters, Andover, UK; [d]Land Division, Defence Science and Technology Group, Melbourne, Australia

Measure	Internal/External
Diaries and Training Logs	External (descriptive)
Direct Observations	External (descriptive)
Oxygen Consumption	Internal (metabolic)
Accelerometry	External (kinematic)
Global Positioning Devices	External (kinematic)
Heart Rate	Internal (cardiovascular)
Doubly Labelled Water	Internal (metabolic)
Biomarkers	Internal (load)
Subjective Self-Report Measures	External (perceptual)

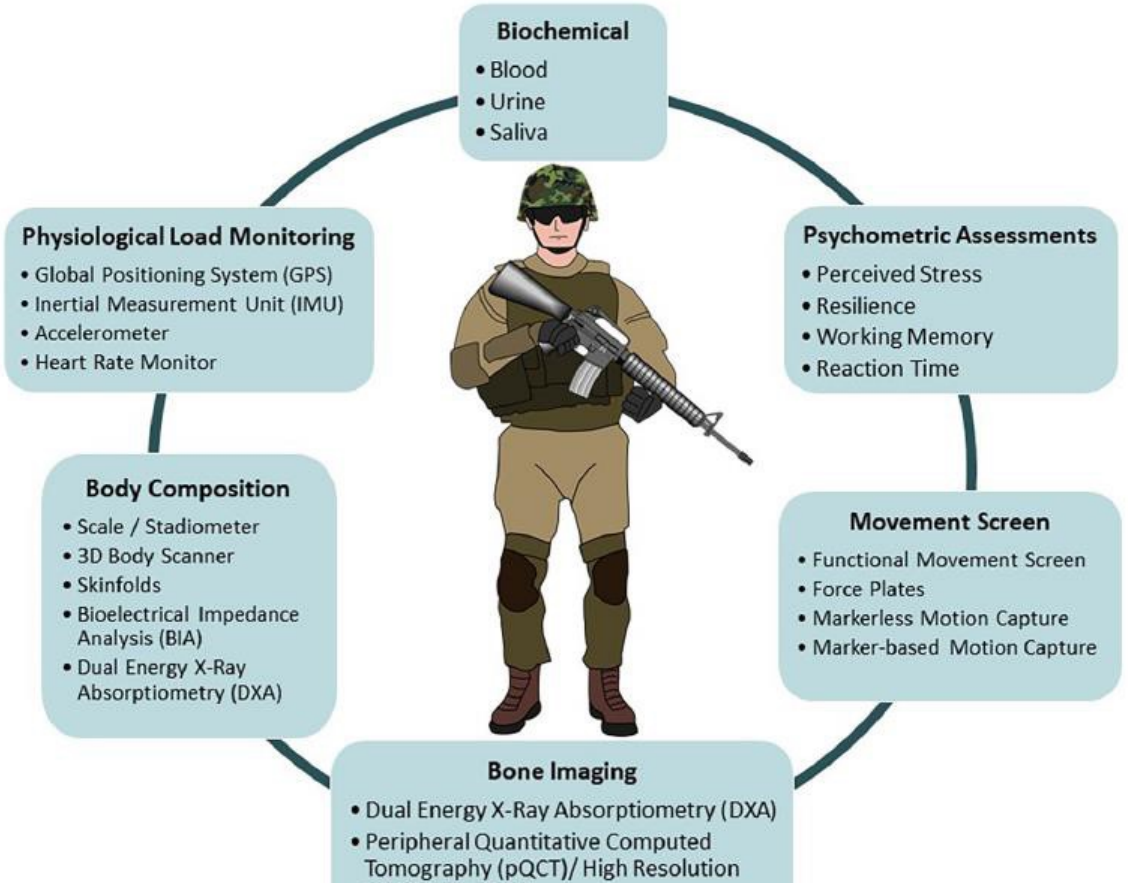
Review

Physiological biomarker monitoring during arduous military training: Maintaining readiness and performance

JSAMS 2023

Kristen J. Koltun *, Matthew B. Bird, Jennifer N. Forse, Bradley C. Nindl

Neuromuscular Research Laboratory/Warrior Human Performance Research Center, Department of Sports Medicine and Nutrition, University of Pittsburgh, United States of America



The Appropriate Use of Science and Technology to Understand and Enhance Military Readiness, Resilience, and Lethality is a 21st Century Imperative

VALID and RELIABLE

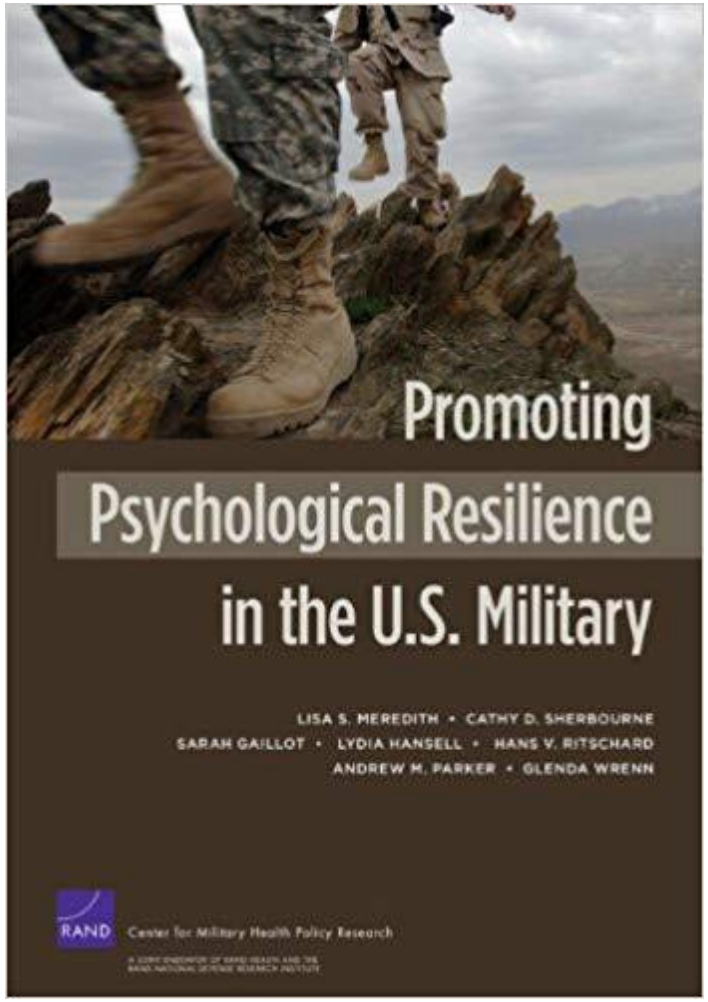
- Must provide actionable information for Military Leadership in the form of dashboards/decision aids/algorithms
- Must be implementable in arduous field environments
- Must be an integrated, holistic, comprehensive, multi-disciplinary, team-centric approach involving all stakeholders to make significant impact
- Must leverage advances in wearable technologies
- Must involve and capitalize on data analytics

What is *resilience*?

- Literature review: **<u>104 definitions</u>** of resilience

- "The demonstration of positive adaptation in the presence of significant adversity"
  - Britt & Sinclair, 2015

- "The capacity to overcome the negative effects of setbacks and associated stress on cognitive function or performance"
  - NMRL, 2017



Unified Vision: Integrated, Holistic, Comprehensive

Body Composition

Blood Biomarkers

Neurobiology

Heart Rate Variability

Range of Motion

Cardiovascular Endurance

Nutrition

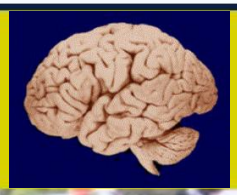
Training Load

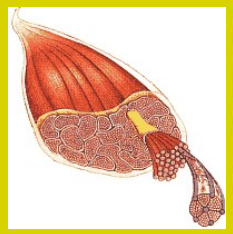
Microbiome

Muscular Strength

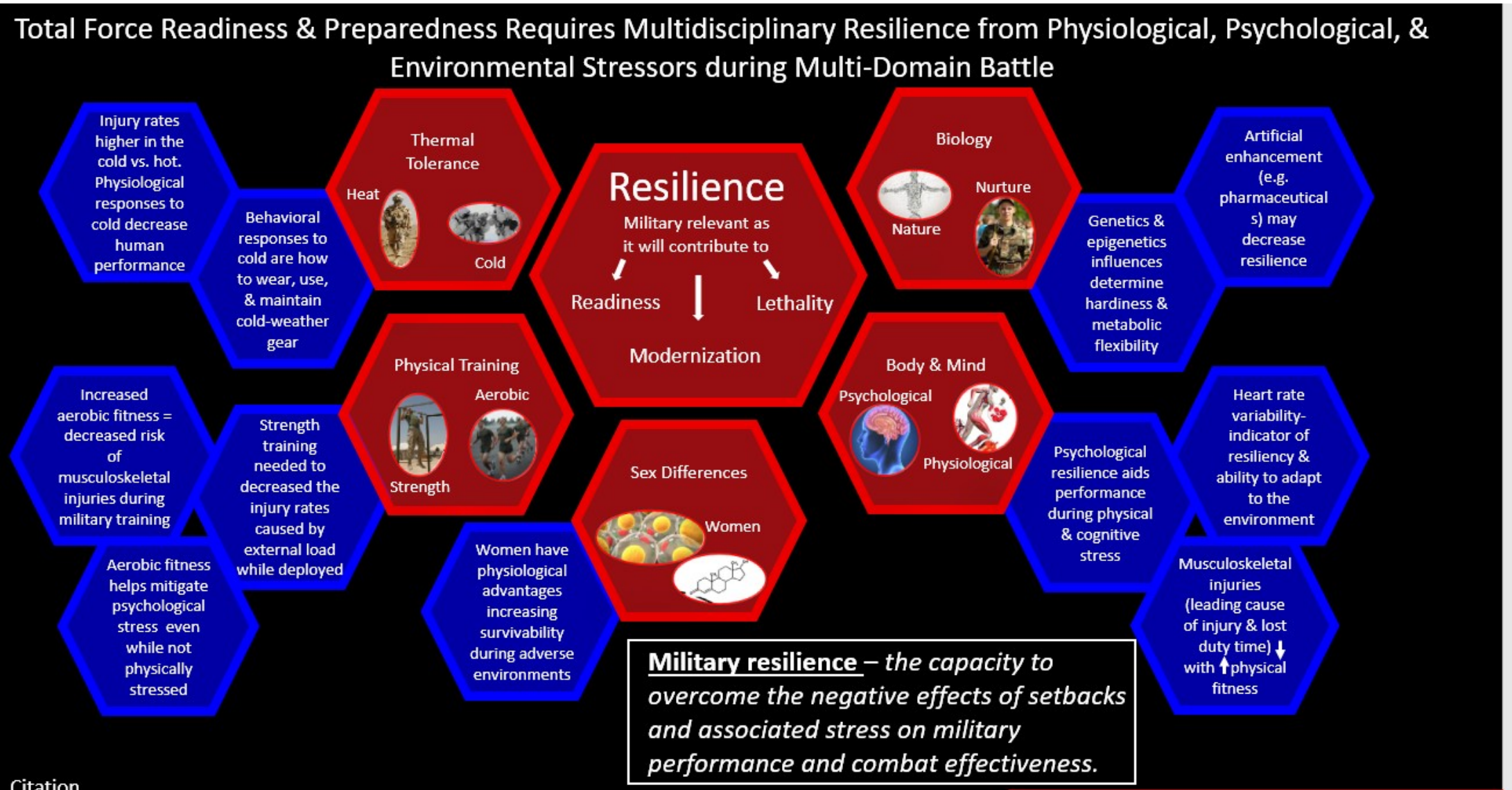
Proprioception

Psychology





Total Force Readiness & Preparedness Requires Multidisciplinary Resilience from Physiological, Psychological, & Environmental Stressors during Multi-Domain Battle



Military resilience – *the capacity to overcome the negative effects of setbacks and associated stress on military performance and combat effectiveness.*

Citation

Nindl, B. C., Billing, D. C., Drain, J. R., Beckner, M. E., Greeves, J., Groeller, H., ... & Taylor, N. A. (2018). Perspectives on resilience for military readiness and preparedness: Report of an international military physiology roundtable. *Journal of science and medicine in sport*.

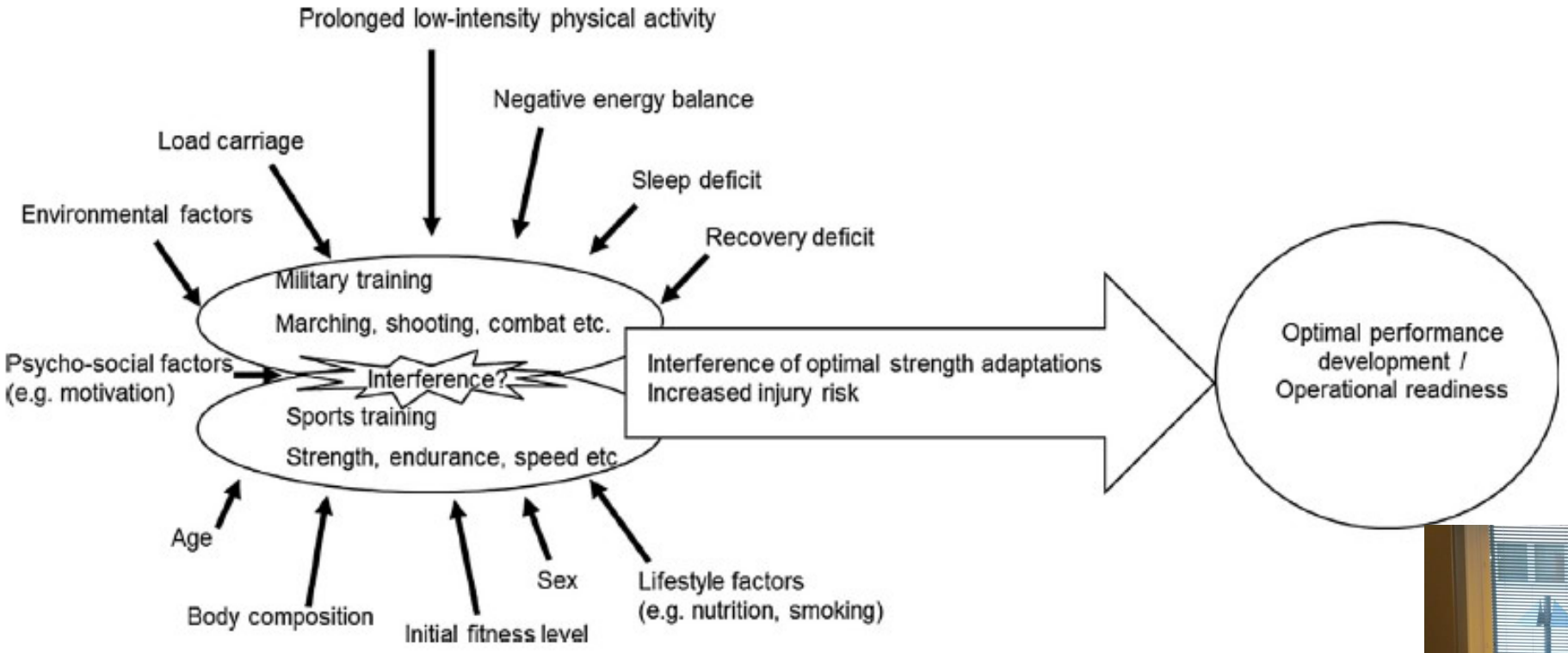
WARFIGHTER APPLICATIONS REVIEW

Review

Optimising training adaptations and performance in military environment

JSAMS, 2018

Heikki Kyröläinen[a,b,*], Kai Pihlainen[c], Jani P. Vaara[b], Tommi Ojanen[d], Matti Santtila[b]



Heikki Kyröläinen, Ph.D., FACSM
Invited Keynote Speaker, 4th ICSPP
Original Co-Founder of ICSPP Series

Human Performance Optimization Metrics: Consensus Findings, Gaps, and Recommendations for Future Research

JSCR, 29(11S): S221-S245, 2015

Bradley C. Nindl,[1,2] Dianna P. Jaffin,[3] Michael N. Dretsch,[4] Samuel N. Cheuvront,[5] Nancy J. Wesensten,[6] Michael L. Kent,[7] Neil E. Grunberg,[3] Joseph R. Pierce,[1] Erin S. Barry,[3] Jonathan M. Scott,[3] Andrew J. Young,[5] Francis G. O'Connor,[3] and Patricia A. Deuster[3]

150 Metrics Across 7 Domains:

Physical Fitness (29)

Nutrition (24)

Psychological (36)

Cognitive (35)

Environmental (12)

Sleep (9)

Pain (5)

Human Dimension Proof of Concept
Athletic Performance Portfolio Prioritization
Pentagon Meeting Feb 2016

- 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

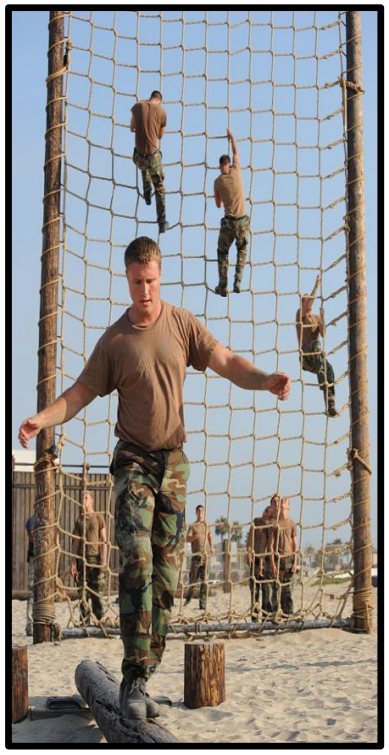
Human Dimension Proof of Concept
Athletic Performance Portfolio Prioritization
Pentagon Meeting Feb 2016

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

Human Dimension Proof of Concept
Athletic Performance Portfolio Prioritization
Pentagon Meeting Feb 2016

- Evaluation Criteria
  - Relevance (27)
  - Scalability (12)
  - Ease of Implementation (15)
  - Effectiveness (25)
  - Assessment Plan (8)
  - Potential Cost Avoidance (7)
  - Efficiency (6)

Functional Tactical-Related Metrics



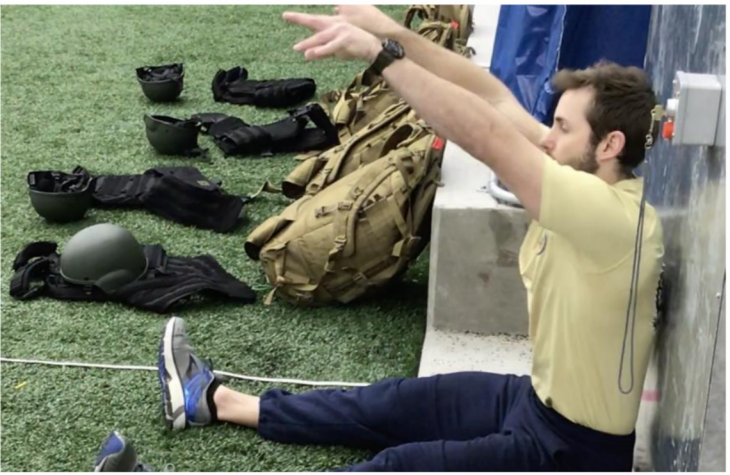
Obstacle Course

Task Simulation

Y-balance Test

Nindl et al., JSCR

PES Test Outcomes







Development of the Tactical Human Optimization, Rapid Rehabilitation, and Reconditioning Program Military Operator Readiness Assessment for the Special Forces Operator

Ray Bear
HPC, 3rd SFG

Strength and Conditioning, 2016

11 Tactically Relevant and Physically Taxing Events

Repetitive Boxlifting Test

PHOTO 1

PHOTO 2

PHOTO 3

International Journal of
Environmental Research and Public Health

MDPI

Article

Training-Induced Acute Neuromuscular Responses to Military Specific Test during a Six-Month Military Operation

Kai Pihlainen [1,*], Arto J Pesola [2], Joonas Helén [3], Keijo Häkkinen [4], Taija Finni [4], Tommi Ojanen [5], Jani P. Vaara [3], Matti Santtila [3], Jani Raitanen [6,7] and Heikki Kyröläinen [3,4]

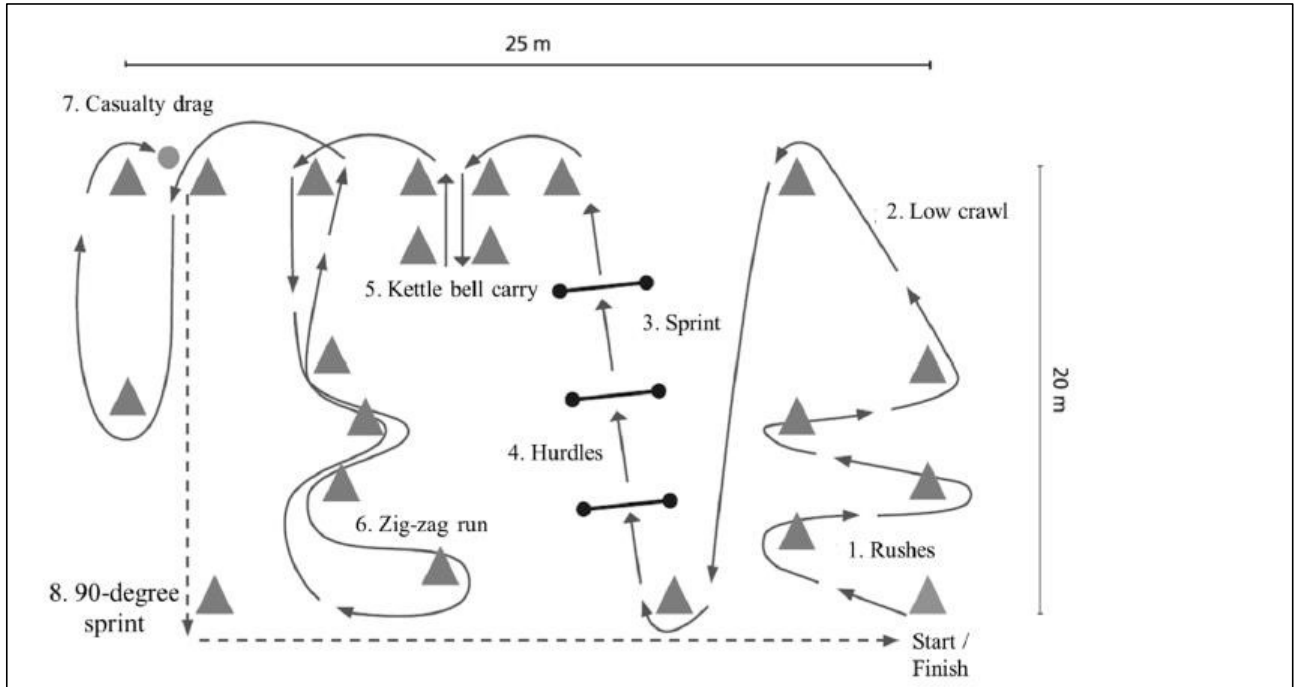


Figure 1. Illustration of the military simulation test track, including eight tasks (1–8) of the test

Strength & Power Assessment

- 1RMs: squat, BP, HP
- Explosive Jump Squats
- Explosive Bench Throws

- 30% of 1RM

  Peak Power (PP)
  Mean Power (MP)
  Rate of Force Development (RFD)

Plyometric Power Machine

Squat Endurance Test

Absolute Endurance Test

100 LBS (45.36 kg)

36.2 cm displacement

37.5 repetitions/minute

2013 National Strength and Conditioning Association's 2nd Blue Ribbon Panel on Military Physical Readiness: Military Physical Performance Testing

- Jump or leap over obstacles
- Move with agility-coordination
- Carry heavy load
- Drag heavy load
- Run long distance
- Move quickly short distances
- Climb over obstacles
- Lift heavy objects
- Load/stow/mount hardware

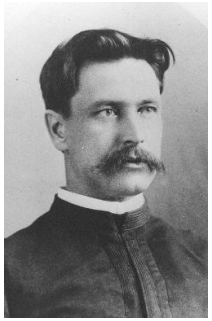
2013 National Strength and Conditioning Association's 2nd Blue Ribbon Panel on Military Physical Readiness: Military Physical Performance Testing

- Health-Related Fitness
  - Body Composition
  - Cardiovascular Fitness
  - Flexibility
  - Muscular Strength
  - Muscular Endurance
- Skill-Related Fitness
  - Speed
  - Agility
  - Balance
  - Coordination
  - Reaction Time
  - Power

1. Strength
2. Power
3. Endurance
4. Body Composition
5. Coordination
6. Balance
7. Agility
8. Flexibility
9. Aerobic
10. Speed
11. Reaction time

History of U.S. Army Physical Training

- COL Herman J. Koehler considered the “Father of Army Physical Training”
  - Gymnastics background.
  - COL Koehler began his tenure at West Point in 1885.
  - Much of the training was based upon methods for improving mechanical efficiency through calisthenics and gymnastics, just as he had learned in his youth.



- President Teddy Roosevelt understood the importance of physical preparedness.
  - In 1907 he ordered annual physical tests of all field officers in the Army. This test included either 3 consecutive days of riding horseback 30 miles on each day, or a 50 mile foot march to be made in 3 consecutive days and taking no more than 20 hours including rests.

ARMY Magazine - April 2017 - page 41

Holistic Health and Fitness: A Better Way to Readiness

By Maj. Gen. Anthony C. Funkhouser

Holistic Health and Fitness (H2F) is combination of doctrine and specific techniques design to address our warriors challenges by improving performance, cognitive dominance and resilience across the force. The Master Fitness Trainer Course (MFTC) is preparing it's candidates in the science and application of strength and condition fundamentals that foster H2F principles into the Army's physical readiness

FM 7-22

HOLISTIC HEALTH AND FITNESS

OCTOBER 2020

DISTRIBUTION RESTRICTION:

Approved for public release; distribution is unlimited.

This publication supersedes chapters 1–6 and appendix D of FM 7-22, dated 26 October 2012.

HEADQUARTERS, DEPARTMENT OF THE ARMY

Soldier Lethality

Physical Readiness			Mental Toughness	
Governance	**Program**	**Equipment and Facilities**	**Personnel**	**Leader Education**
Command and control Regulations, policies, and doctrine Strategic program assessment Quality assurance Accountability Resourcing	Individualized, METL-driven, periodized training and testing Physical and non-physical performance readiness Prevention, rehabilitation, and far-forward treatment	Soldier Performance Readiness Center Performance metrics systems Army Combat Fitness Test equipment and field Deployable performance equipment Treatment sets	Physical therapist Occupational therapist Registered dietitian Strength and endurance coach Athletic trainer Holistic health and fitness coach	Initial military training Army Physical Fitness School Professional military education Civilian certification Undergraduate and graduate education

ARMY COMBAT FITNESS TEST EVENTS

3 REPETITION MAXIMUM DEADLIFT (MDL)

STANDING POWER THROW (SPT)

HAND-RELEASE PUSH-UP (HRP)

SPRINT-DRAG-CARRY (SDC)

LEG TUCK (LTK)

TWO-MILE RUN (2MR)

Paavo Nurmi

“I don’t run naked”

“Soldiers don’t go into combat with t-shirts and shorts”

VOLUME 31 | NUMBER 10 | OCTOBER 2017 the Journal of Strength and Conditioning Research™ | www.nsca.com

BIOMARKERS IN SPORTS AND EXERCISE: TRACKING HEALTH, PERFORMANCE, AND RECOVERY IN ATHLETES

ELAINE C. LEE,[1] MAREN S. FRAGALA,[2] STAVROS A. KAVOURAS,[3] ROBIN M. QUEEN,[4] JOHN LUKE PRYOR,[5] AND DOUGLAS J. CASA[1]

DIET

TRAINING

Analysis:
Comprehensive Biomarker Panel

PERFORMANCE
HEALTH
RECOVERY

Nutrition	Glucose, Cholesterol, Lipids, Total protein
Hydration status	BUN: blood creatinine, urine osmolality
Muscle status	Testosterone, DHEA, IGF-I, SHBG, LH, Cortisol
Cardiovascular Endurance	Hemoglobin, Transferrin, total iron concentration
Injury Risk	Bone mineral density, CRP, cytokines, IGF-I
Inflammation	IL-1β, IL-6, IL-10, CBC/diff

EUROPEAN JOURNAL OF SPORT SCIENCE
https://doi.org/10.1080/17461391.2021.1962983

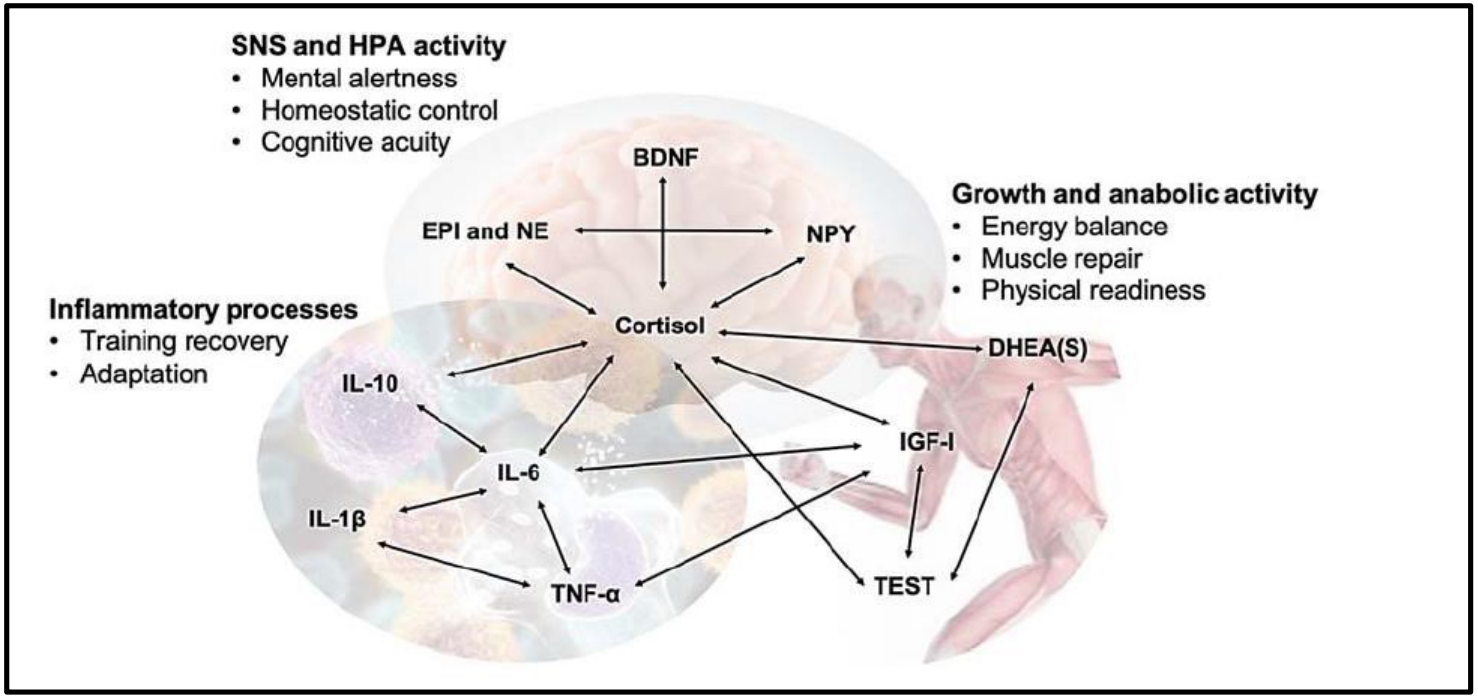
Routledge
Taylor & Francis Group

REVIEW

Circulating biomarkers associated with performance and resilience during military operational stress

Meaghan E. Beckner [a], Luana Main [b], Jamie L. Tait [c], Brian J. Martin [a], William R. Conkright [a] and Bradley C. Nindl [a]

[a]Neuromuscular Research Laboratory/Warrior Human Performance Research Center. Department of Sports Medicine and Nutrition, University of Pittsburgh, Pittsburgh, PA, USA; [b]Institute for Physical Activity and Nutrition (IPAN), School of Exercise and Nutrition Sciences, Deakin University, Geelong, Australia; [c]School of Exercise and Nutrition Sciences, Deakin University, Geelong, Australia



- Biomarker panel more appropriate than single hormone
- Real-time physiological monitoring
- Early identification and intervention for at risk-Soldiers to improve resiliency

DIABETES TECHNOLOGY & THERAPEUTICS
Volume 5, Number 3, 2003

Measurement of Insulin-Like Growth Factor-I During Military Operational Stress via a Filter Paper Blood Spot Assay

BRADLEY C. NINDL, Ph.D.,[1] MARK D. KELLOGG, Ph.D.,[2] M. JAVAD KHOSRAVI, Ph.D.,[3,4] ANASTASIA DIAMANDI, Ph.D.,[3] JOSEPH A. ALEMANY, B.S.,[1] DIANE M. PIETILA, M.S.,[1] ANDREW J. YOUNG, Ph.D.,[2] and SCOTT J. MONTAIN, Ph.D.[2]

Am J Physiol Regul Integr Comp Physiol 303: R1080–R1089, 2012.
First published August 29, 2012; doi:10.1152/ajpregu.00275.2012.

IGF-I measurement across blood, interstitial fluid, and muscle biocompartments following explosive, high-power exercise

Bradley C. Nindl,[1]* Maria L. Urso,[1]* Joseph R. Pierce,[1] Dennis E. Scofield,[1] Brian R. Barnes,[1] William J. Kraemer,[2] Jeffrey M. Anderson,[2] Carl M. Maresh,[2] Kathleen N. Beasley,[1] and Edward J. Zambraski[1]

Innovative Methodology

Am J Physiol Regul Integr Comp Physiol 300: R1326–R1332, 2011.
First published March 9, 2011; doi:10.1152/ajpregu.00313.2010.

A novel, noninvasive transdermal fluid sampling methodology: IGF-I measurement following exercise

D. E. Scofield,[1] H. L. McClung,[2] J. P. McClung,[2] W. J. Kraemer,[3] K. R. Rarick,[1] J. R. Pierce,[1] G. J. Cloutier,[4] R. A. Fielding,[4] R. W. Matheny, Jr.,[1] A. J. Young,[2] and B. C. Nindl[1]

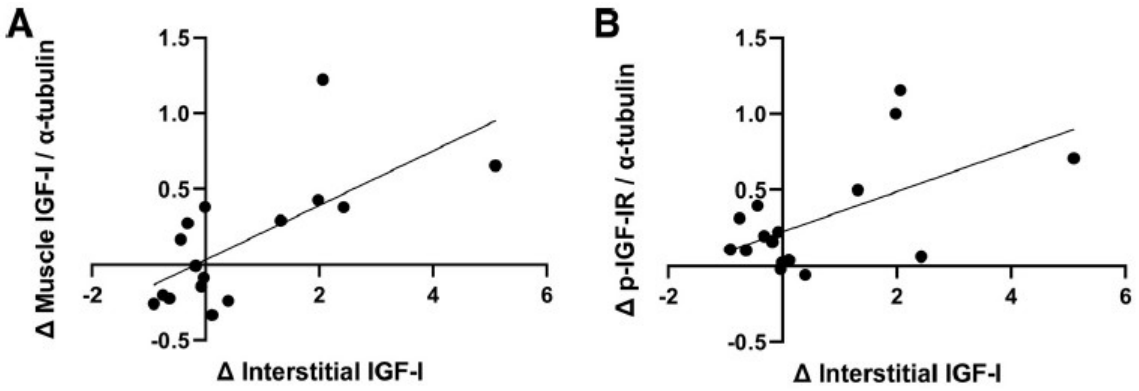
RESEARCH ARTICLE

Insulin-like growth factor-I biocompartmentalization across blood, interstitial fluid and muscle, before and after 3 months of chronic resistance exercise

Adam J. Sterczala,[1] Joseph R. Pierce,[2] Brian R. Barnes,[2] Maria L. Urso,[2] Ronald W. Matheny,[2] Dennis E. Scofield,[2] Shawn D. Flanagan,[1] Carl M. Maresh,[3] Edward J. Zambraski,[2] William J. Kraemer,[3,4] and Bradley C. Nindl[1,2]

Microdialysis-Assessed Exercised Muscle Reveals Localized and Differential IGFBP Responses to Unilateral Stretch Shortening Cycle Exercise

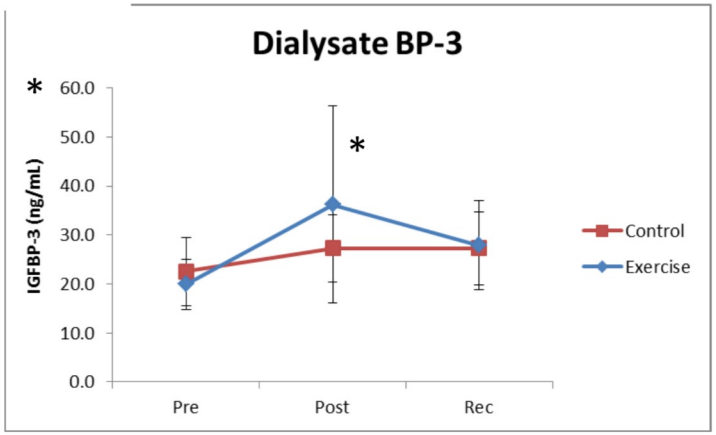
Bradley C. Nindl[1,2,3], Juha Ahtiainen[4], Sheila S. Gagnon[4], Ritva S. Taipale[4], Joseph R. Pierce[2,3], Brian J. Martin[1], Meaghan E. Beckner[1], M. Lehti[4], Keijo Häkkinen[4] and Heikki Kyröläinen[4]*

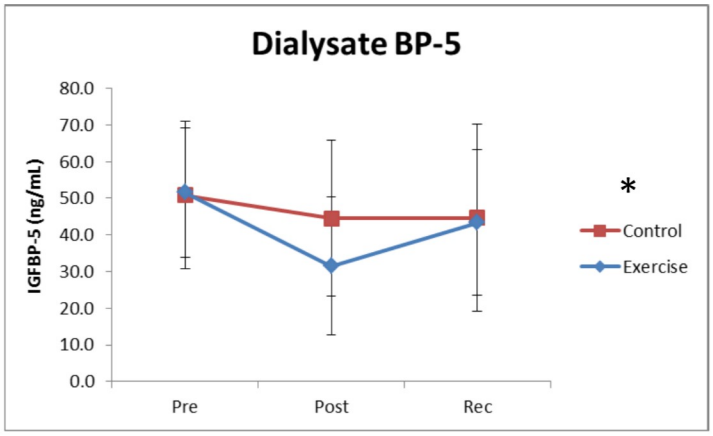


Microdialysis-Assessed Exercised Muscle Reveals Localized and Differential IGFBP Responses to Unilateral Stretch Shortening Cycle Exercise

Bradley C. Nindl[1,2,3], Juha Ahtiainen[4], Sheila S. Gagnon[4], Ritva S. Taipale[4], Joseph R. Pierce[2,3], Brian J. Martin[1], Meaghan E. Beckner[1], M. Lehti[4], Keijo Häkkinen[4] and Heikki Kyröläinen[4]*

Front Endo, 2020





ISF Measures:

No change in IGF-I

Increased IGFBP-3

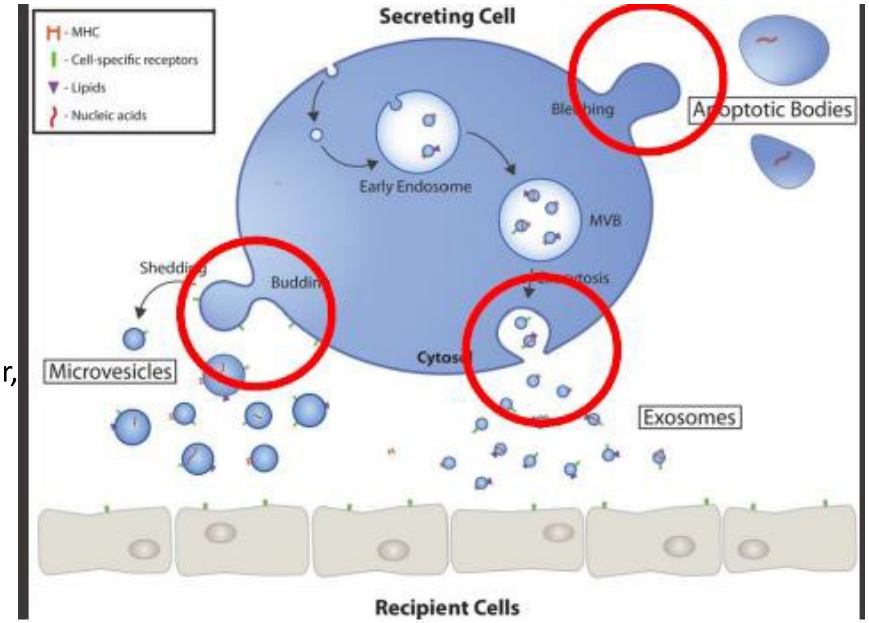
Decreased IGFBP-5

<u>Influenced by load</u>

Extracellular Vesicles (EVs)

An unexplored biomarker in military operational stress

- **EVs are a "universal vehicle"**
  - Released by nearly all cell types (Tetta et al., 2013)
  - Can be isolated from various body fluids (Thery et al., 2018)
- **EVs provide a "comprehensive package"**
  - Protective lipid-bilayer during transport (Beninson & Fleshner, 2014)
  - Transfer biological contents between cells
  - EV cargo mirrors genetic and proteomic content of parent cell (Akers et al., 2013)



Cognitive Resilience Study

1. Psychological Battery

-Personality

-Resilience

-Coping Styles

-Depression

-PTSD

2. Neurocognitive Battery

-Sensorimotor Speed
-Spatial Learning
-Memory
-Abstraction
-Concept Formation
-Spatial Orientation
-Emotion Identification
-Abstract Reasoning
-Visual Tracking
-Risk Decisions
-Attention

NASA

3. Psychomotor Battery

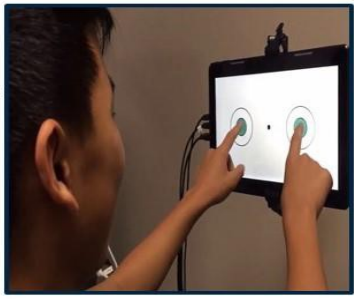
-Dynamic Visual Acuity

-Depth Perception

-Perception Span

-Multiple Object Tracking

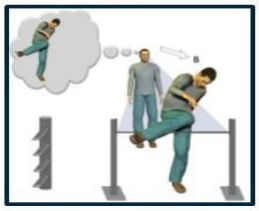
-Reaction Time



4. Sensorimotor Battery

-Obstacle Cross

-Perception Action Coupling Task



5. Tactical Battery

-Marksmanship

-Adaptive Decision Making

-Tactical Movements

6. Sleep Battery

-High-density EEG

-Breathing Rate

-Actigraphy

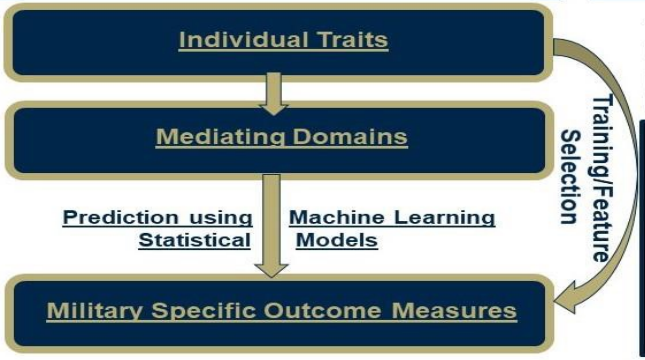
-Electrocardiogram

7. Physiological Battery

-Blood Biomarkers

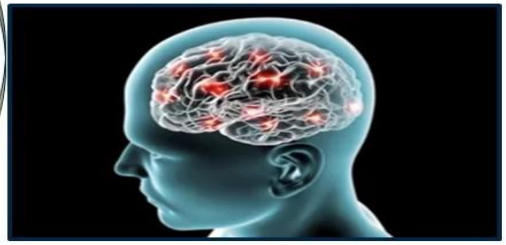
-Transcranial Magnetic Stimulation
  -Motor evoked potentials
  -Cortical Silent periods
- Heart-Rate Variability
- Aerobic Capacity
- Maximal Jumping Performance
- Maximal Contractile Force

MACHINE LEARNING ANALYSIS



DELIVERABLES

-Valid and reliable toolkit of cognitive metrics related to military tactical performance operationalized in a meaningful and military-relevant manner



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Physiology & Behavior

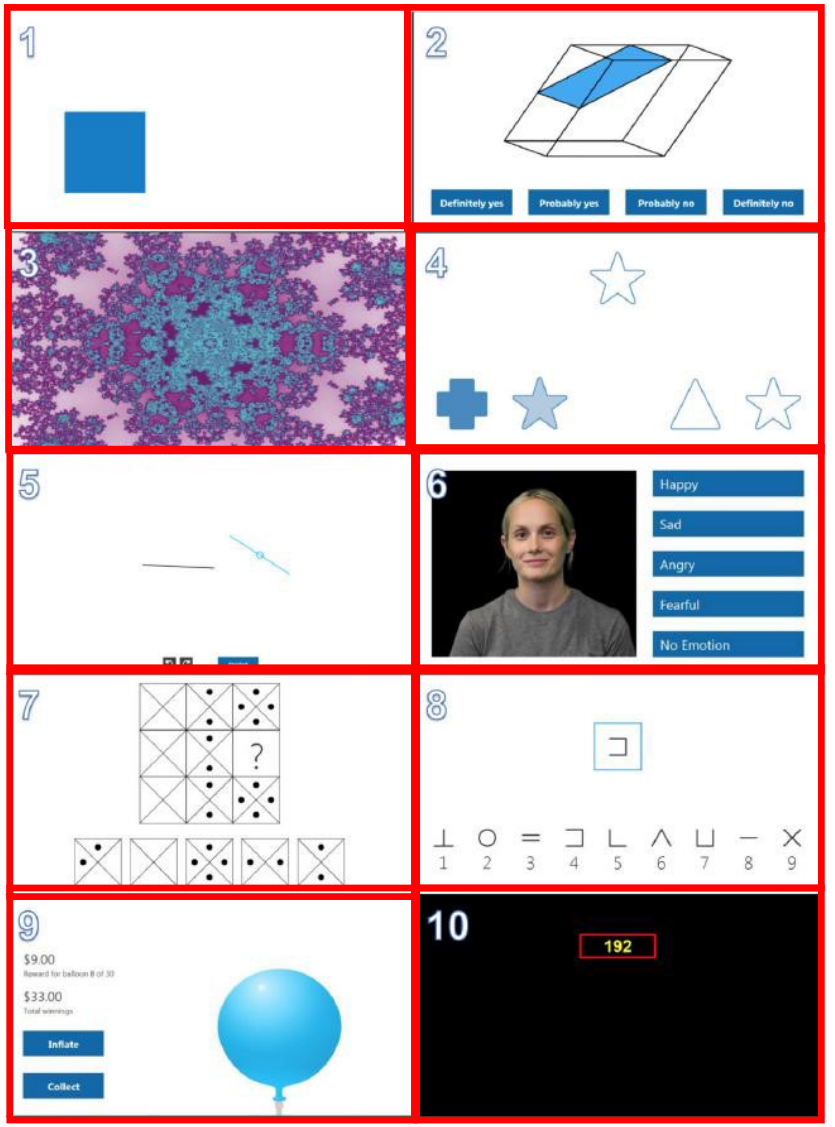
journal homepage: www.elsevier.com/locate/physbeh

Impact of simulated military operational stress on executive function relative to trait resilience, aerobic fitness, and neuroendocrine biomarkers

Meaghan E. Beckner [a,*], William R. Conkright [a], Shawn R. Eagle [a], Brian J. Martin [a], Aaron M. Sinnott [a], Alice D. LaGoy [a,b], Felix Proessl [a], Mita Lovalekar [a], Leslie R. Jabloner [a], Peter G. Roma [c], Mathias Basner [d], Fabio Ferrarelli [b], Anne Germain [b], Shawn D. Flanagan [a], Christopher Connaboy [a], Bradley C. Nindl [a]

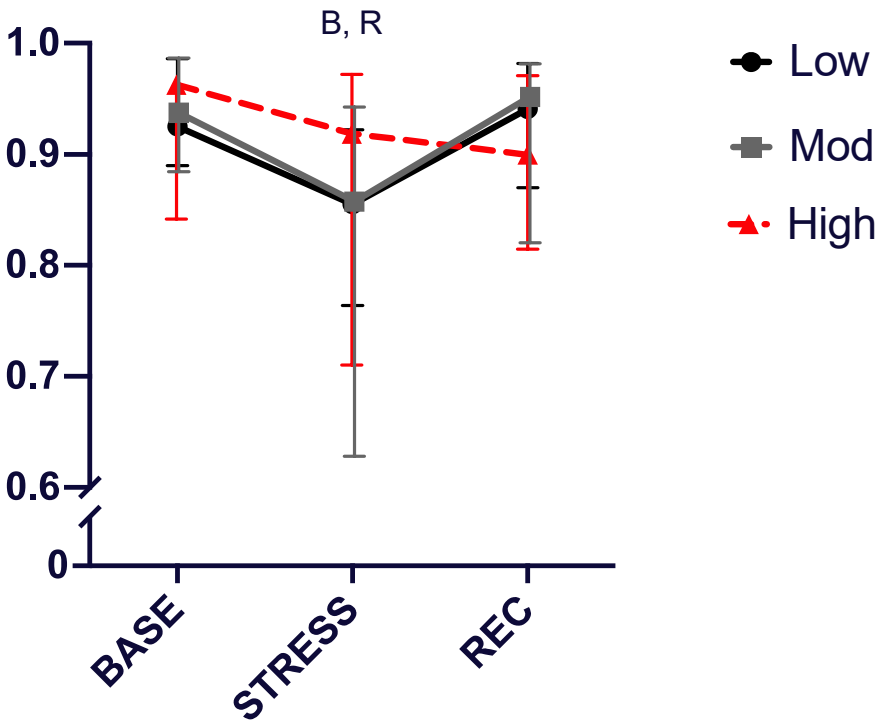
Cognition Test Battery

1. Motor Praxis
2. Visual Object Learning
3. Fractal 2-Back
4. Abstract Matching
5. Line Orientation
6. Emotion Recognition
7. Matrix Reasoning
8. Digital Symbol Substitution
9. Balloon Analog Risk
10. Psychomotor Vigilance



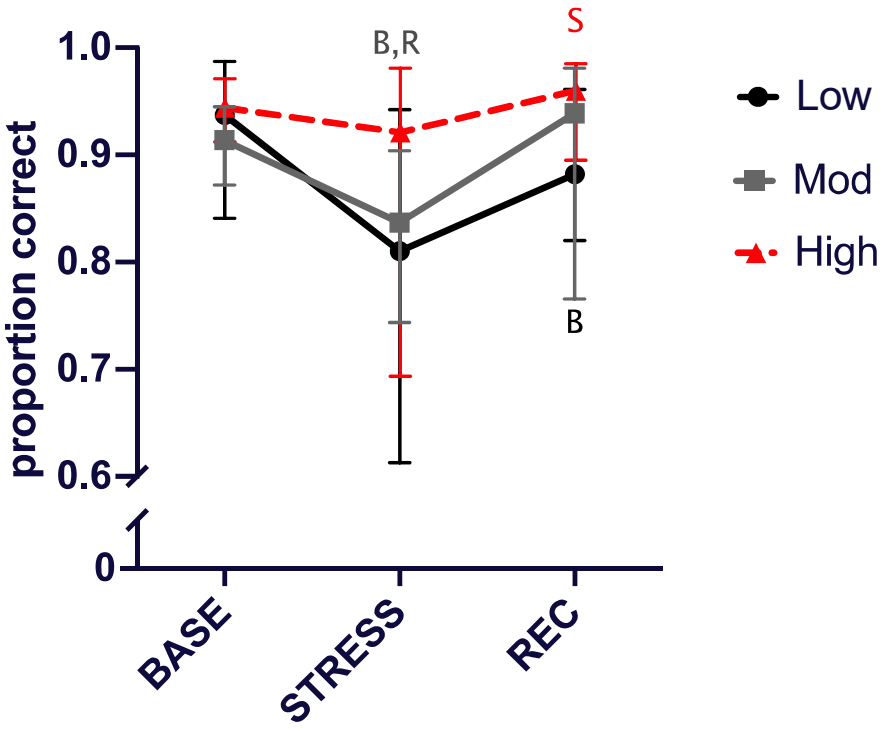
Median ± IQR

PVT Accuracy by CD-RISC



- Low: CD-RISC ≤ 79
- Mod: CD-RISC >79, ≤ 90
- High: CD-RISC > 90

PVT Accuracy by VO_{2peak}



- Low: $\dot{V}O_{2peak} \leq 44.87$ mL·kg^{-1}·min^{-1}
- Mod: $\dot{V}O_{2peak} > 44.87, \leq 51.53$ mL·kg^{-1}·min^{-1}
- High: $\dot{V}O_{2peak} > 51.53$ mL·kg^{-1}·min^{-1}

Military Tactical Adaptive Decision Making During Simulated Military Operational Stress Is Influenced By Personality, Resilience, Aerobic Fitness And Neurocognitive Function

Nicole M. Sekel[1], Meaghan E. Beckner[1], William R. Conkright[1], Alice D. LaGoy[1,4], Felix Proessel[1], Mita Lovalekar[1], Brian J. Martin[1], Leslie R. Jabloner[1], Alaska L. Beck[1], Shawn R. Eagle[1], Michael Dretsch[5], Peter G. Roma[2,6], Fabio Ferrarelli[4], Anne Germain[4], Shawn D. Flanagan[1], Christopher Connaboy[1], Amy Haufler[3], Bradley C. Nindl[1]

Original Research

the Journal of Strength and Conditioning Research™

Neuromuscular Performance and Hormonal Responses to Military Operational Stress in Men and Women

William R. Conkright,[1] Meaghan E. Beckner,[1] Aaron M. Sinnott,[1] Shawn R. Eagle,[1] Brian J. Martin,[1] Alice D. Lagoy,[1,2] Felix Proessl,[1] Mita Lovalekar,[1] Tim L.A. Doyle,[3] Phil Agostinelli,[1] Nicole M. Sekel,[1] Shawn D. Flanagan,[1] Anne Germain,[2] Christopher Connaboy,[1] and Bradley C. Nindl[1]

Table 2

Tactical mobility test events during 5 days of simulated military operational stress.*

Event	Group	Day 1: baseline	Day 2: stress onset	Day 3: peak stress	Day 4: recovery	Main effect of day p (partial η^2)	Main effect of sex p (partial η^2)
WCC ($m \cdot s^{-1}$)	Men	1.53 ± 0.38	1.56 ± 0.32	1.50 ± 0.39	1.50 ± 0.33	0.173 (0.027)	<0.001 (0.327)
	Women	0.98 ± 0.35	1.07 ± 0.42	0.96 ± 0.31	1.00 ± 0.37		
FM (s)	Men	145.6 ± 13.1	148.8 ± 16.1	146.5 ± 16.0	148.8 ± 16.6	0.119 (0.032)	0.020 (0.083)
	Women	152.5 ± 13.3	157.4 ± 19.2	150.7 ± 17.0	145.7 ± 15.2		
CD (s)	Men	41.5 ± 23.5	40.0 ± 13.7	39.8 ± 14.2	43.6 ± 11.3	0.129 (0.030)	<0.001 (0.374)
	Women	82.0 ± 32.2	72.7 ± 23.1	67.5 ± 11.0	67.1 ± 15.3		
300US (s)	Men	95.5 ± 18.5	98.3 ± 19.1	102.0 ± 21.7†	102.5 ± 18.4†	0.001 (0.084)	0.017 (0.087)
	Women	109.1 ± 14.8	109.8 ± 15.7	113.3 ± 16.7†	113.5 ± 17.9†		
300LS (s)	Men	117.5 ± 25.8	117.1 ± 28.5	117.7 ± 28.5	119.5 ± 25.8	0.440 (0.015)	0.130 (0.038)
	Women	128.9 ± 19.8	128.9 ± 21.4	133.5 ± 23.7	130.3 ± 18.8		
RM (s)	Men	1,661.4 ± 385.2	1,617.2 ± 313.5	1,631.0 ± 322.3	1,545.2 ± 323.5	0.127 (0.036)	0.881 (<0.001)
	Women	1,659.9 ± 149.8	1,599.4 ± 138.6	1,645.8 ± 252.5	1,604.7 ± 146.5		

*WCC = water can carry; FM = fire and movement; CD = casualty drag; 300US = 300-m unloaded shuttle run; 300LS = 300-m loaded shuttle run; RM = ruck march.
†Significantly different than baseline. Data are presented as mean ± *SD*. Significance was set at $p < 0.05$.

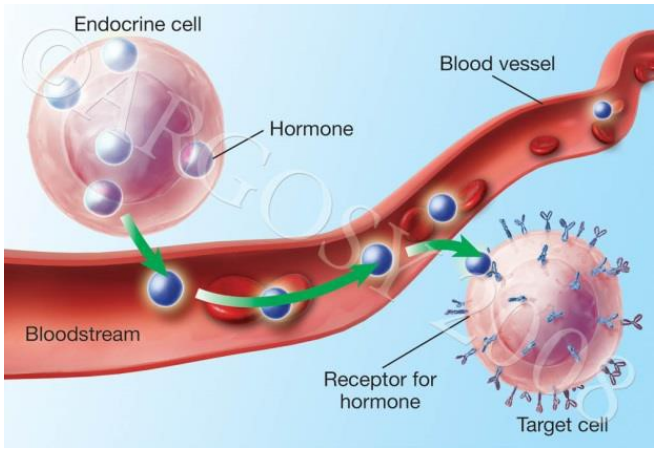
ORIGINAL ARTICLE

The Physiological Society | american physiological society | Physiological Reports

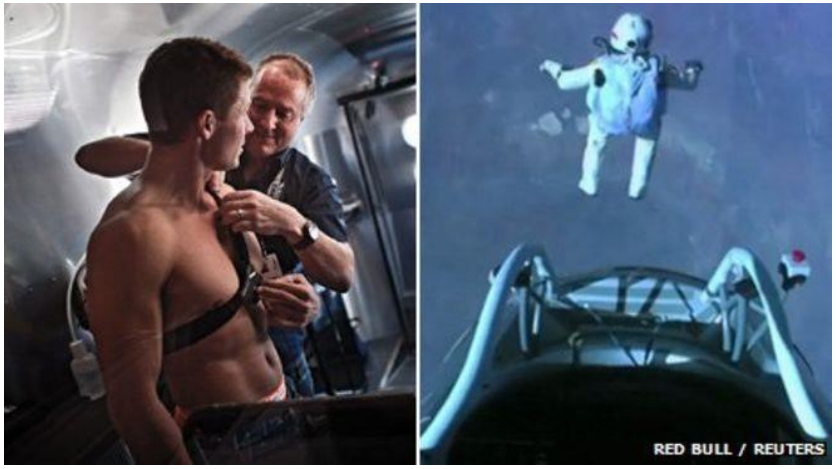
Utility of extracellular vesicles as a potential biological indicator of physiological resilience during military operational stress

Meaghan E. Beckner[1] | William R. Conkright[1] | Amrita Sahu[2] | Qi Mi[1] | Zachary J. Clemens[2] | Brian J. Martin[1] | Shawn D. Flanagan[1] | Fabio Ferrarelli[3] | Fabrisia Ambrosio[2,4] | Bradley C. Nindl[1]

- Neuroendocrine biomarkers unable to differentiate trait-resilience
- In response to stress, high trait-resilience:
  - Greater heterogeneity among large-sized THSD1^{+} EVs
  - Greater decrease in side-scatter minimum pixel intensity
- Presence of physiological adaptations among high trait-resilient individuals



Leveraging Wearable Technologies



High Performance Model

- Commercial grade technology to assess performance and musculoskeletal injuries (MSKI) have been fully integrated into the High Performance Model for Olympic, professional and NCAA athletics
  - Force Plates, Questionnaires, GPS tracking, Urine and saliva samples to track physical and psychological readiness.

	Bases/Teams	Total Soldiers/Players	Ratio
Army Active Components	31 Bases	378,900 Active Component Soldiers	12,222 soldiers per base
National Football Organization	32 Teams	1,696 Active Roster Players	53 Players per team

Military Applications

- Assess injury risk
  - Suboptimal biomechanical patterns (xsens, DARI)
  - Estimate overexertion/overtraining (Catapult, Equivital)
- Streamline rehabilitation with objective data
  - Identify muscular asymmetries (DARI)
  - Identify physiological readiness (Catapult, Equivital)
- Optimize performance
  - Individualize training programs to target specific deficits

Screening Tests to detect physical readiness

- Consequently, there is a heighted awareness of **screening tests** that can inform military leadership regarding Musculoskeletal injury (MSKI) risk.
- Functional Movement Screen (FMS)
  - 2 systematic reviews = poor predictability. (Moran et. al. 2017, Dorrel et. al. 2015)
- Marked Motion Capture (MoCap)
  - Reserved for “state of the art” science laboratories
- There is a need for **field expedient** measures to accurately demonstrate MSKI risk associations.

1) Developing a Warfighter Mobility Signature and Predictive Algorithm For Musculoskeletal Injury Risk During Marine Corps Officer Candidate School
2) Development of a Physical Readiness Decision Tool to Leverage Wearable Technologies for Monitoring Warfighter's Mobility and Load Exposure

COTS Biomechanical Monitors

Force Plates

DARI

IMTP

Ankle Inclinometer

DEXA Scanner

pQCT

COTS/GOTS Physiological Monitors

ActiGraph

Garmin

SPOT Trace

iMeasureU

Omni Chest Strap

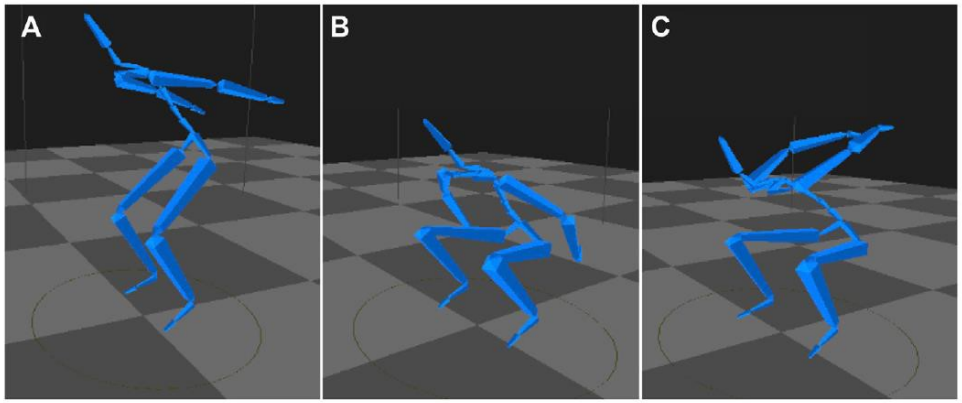
Omni Knee Sleeve

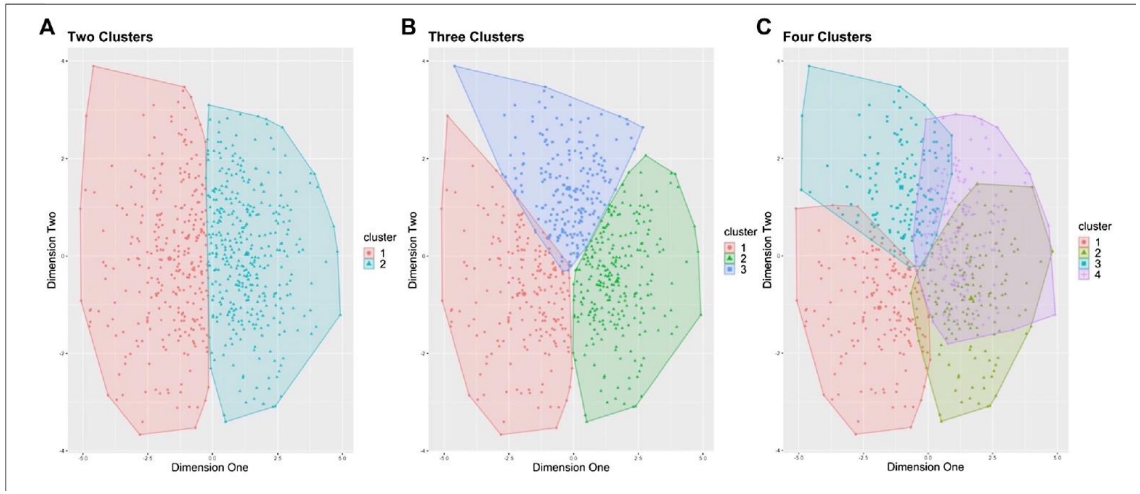
Omni Ankle Sleeve

Movement
DARI Markerless Motion Capture

Movement Screen

- Movement Patterns & Strategies
- Movement Asymmetries
- Joint Range of Motion
- Peak Joint Angles
- Joint Torque & Moments





Unsupervised Clustering Techniques Identify Movement Strategies in the Countermovement Jump Associated With Musculoskeletal Injury Risk During US Marine Corps Officer Candidates School

Bird, et. al. Frontiers in Physiology, 2022

Proportions of MSKI per movement strategy

Table 3. Proportions of MOCs with Lower Body and Torso Musculoskeletal Injury by Cluster

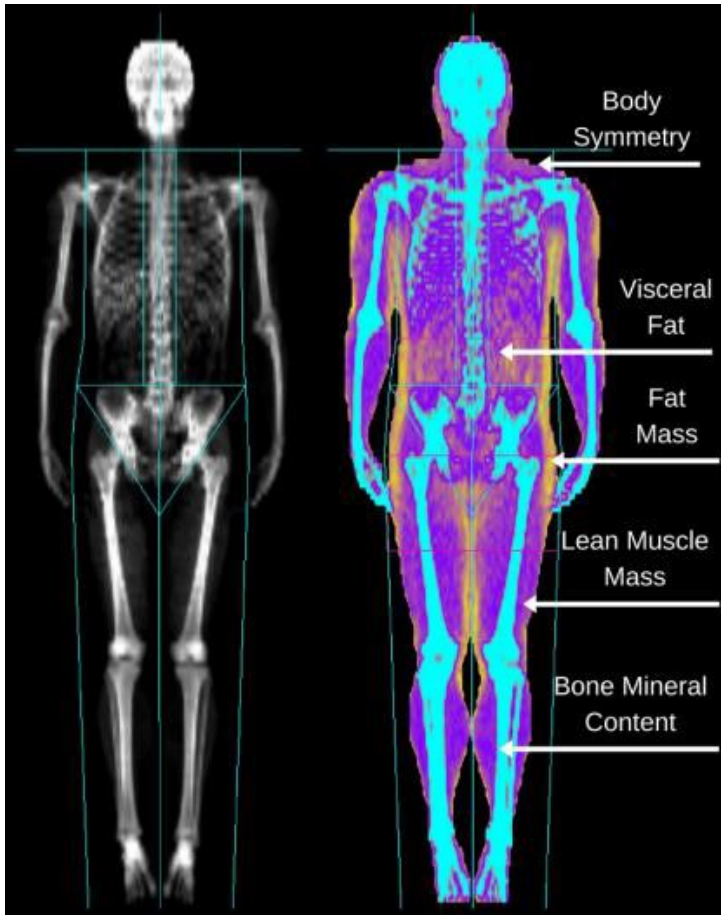
					Relative-Risk (95% CI)		
	C1(low-risk)	C2(moderate-risk)	C3(high-risk)	Fisher's exact test p value	C3/C1	C2/C1	C3/C2
%MSKI	28/203=13.8%	47/209=22.5%	78/256=30.5%	<0.001	2.2(1.5-3.3)	1.6(1.1-2.5)	1.3(1.0-1.9)
%Male MSKI	26/195=13.3%	45/201=22.4%	38/151=25.2%	0.011	1.9(1.2-3.0)	1.7(1.1-2.6)	1.1(0.77-1.6)
%Female MSKI	2/8=25.0%	2/8=25.0%	40/105=38.1%	0.770	1.5(0.5-5.1)	1.0(0.2-5.5)	1.5(0.5-5.1)
%Male	195/203=96.1%	201/209=96.2%	151/256=59.0%	<0.001			
%Female	8/203=3.9%	8/209=3.8%	105/256=41.0%	<0.001			

Thresholds associated with movement strategy

Table 6. Markerless Motion Capture and Force Plate Variables used for K-means Clustering in Marine Officer Candidates

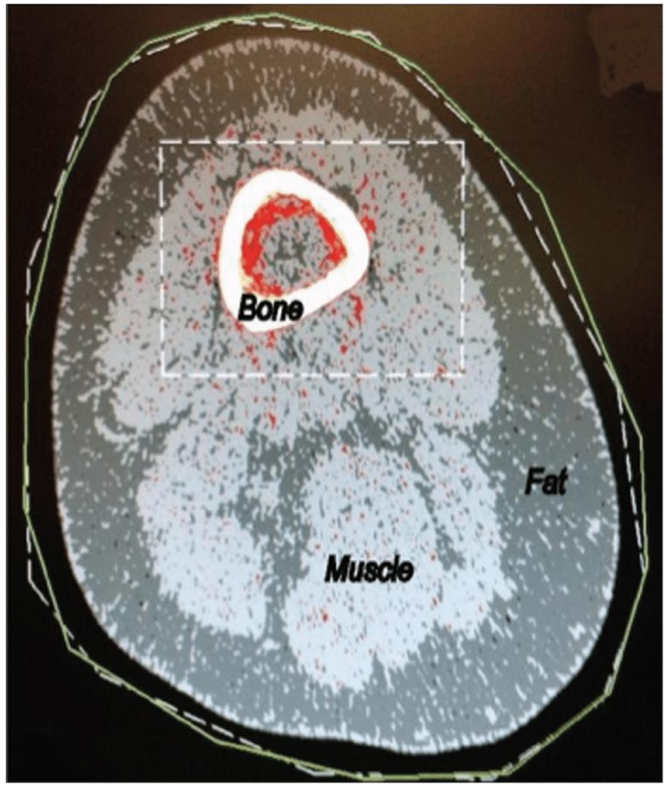
	Abbreviation	C1(low-risk)	C2(moderate-risk)	C3(high-risk)	Omnibus p value	Bonferroni adjusted post hoc pairwise comparison p-value		
						C3,C1	C2,C1	C3,C2
Kinetic Measures								
Braking RFD (N/s)	BRFD	4518±1725	4200±1556	2019±761	<0.001	<0.001	0.057	<0.001
Braking Net Impulse (N*s)	BNI	111±21	122±18	88±16	<0.001	<0.001	<0.001	<0.001
Propulsive Net Impulse (N*s)	PNI	238±33	228±30	180±35	<0.001	<0.001	0.004	<0.001
Peak Relative Propulsive Power (W/kg)	PRPP	59±7	51±6	46±6	<0.001	<0.001	<0.001	<0.001
Kinematic Measures								
Braking Phase (sec)	BP	0.23±0.05	0.27±0.05	0.32±0.07	<0.001	<0.001	<0.001	<0.001
Propulsive Phase (sec)	PP	0.33±0.04	0.40±0.04	0.42±0.05	<0.001	<0.001	<0.001	<0.001
†Max Hip Flexion (degrees)	HF	89.8±15.9	104.3±13.3	102.6±15.6	<0.001	<0.001	<0.001	0.712
†Max Knee Flexion (degrees)	KF	102.6±10.4	126.0±9.4	114.3±13.0	<0.001	<0.001	<0.001	<0.001
†Max Ankle Flexion (degrees)	AF	29.6±4.9	36.8±5.3	33.0±5.6	<0.001	<0.001	<0.001	<0.001
†Dynamic Valgus (degrees)	DV	5.4±2.8	5.5±3.2	6.4±3.4	<0.001	0.002	1.0	0.007

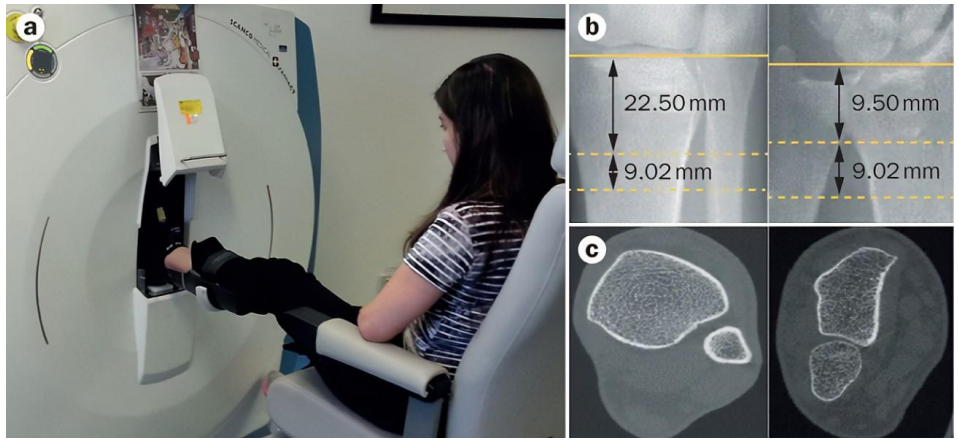
Bone & Body Composition
Dual-Energy X-Ray (DEXA)



- Bone Density
- Body Fat %
- Muscle Mass
- Muscle Imbalances

Bone
Peripheral Quantitative Computed Tomography (HR-pQCT)

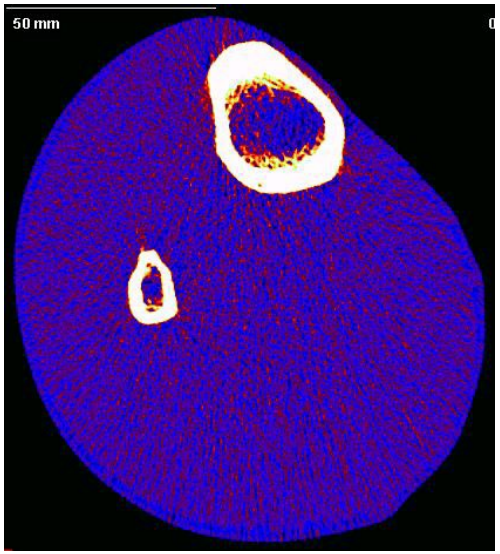




3D Bone Assessment

- Structure
- Composition
- Geometry

TIBIAL CORTICAL GEOMETRY PREDICTS BSI



- Greater bone size indicated by total area, circumference and robustness and were protective against BSI
- Higher estimated strength (SSI) is protective against BSI

66%

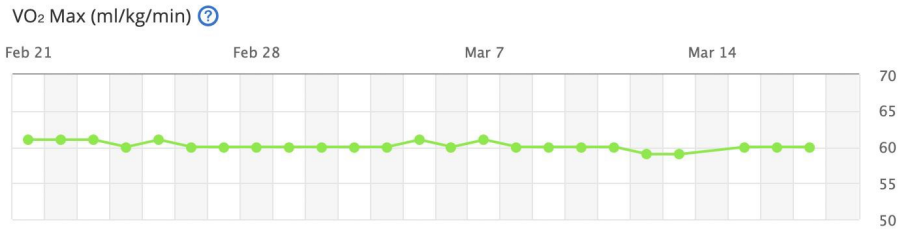
Total vBMD (mg/cm^3)	715.9 ± 66.1	749.4 ± 47.6	1.006 (0.999, 1.014)	0.104	1.006 (0.999, 1.014)	0.105
Total area (mm^2)	631.3 ± 98.1	537.5 ± 73.5	**0.989 (0.982, 0.997)**	**0.004**	**0.985 (0.975, 0.995)**	**0.005**
Cortical vBMD (mg/cm^3)	1107.2 ± 33.8	1116.0 ± 39.0	1.008 (0.988, 1.029)	0.416	1.004 (0.984, 1.025)	0.696
Cortical area (mm^2)	374.0 ± 60.6	337.6 ± 50.1	0.989 (0.978, 1.001)	0.062	0.988 (0.973, 1.003)	0.126
Cortical thickness (mm)	5.1 ± 0.7	5.1 ± 0.5	0.900 (0.355, 2.280)	0.824	1.161 (0.418, 3.226)	0.775
Endosteal circumference (mm)	56.5 ± 6.9	50.0 ± 4.2	**0.855 (0.768, 0.952)**	**0.004**	**0.854 (0.761, 0.960)**	**0.008**
Periosteal circumference (mm)	88.8 ± 7.0	82.0 ± 5.8	**0.867 (0.787, 0.955)**	**0.004**	**0.823 (0.719, 0.941)**	**0.004**
SSI (mm^3)	2995.4 ± 627.1	2458.0 ± 518.9	**0.998 (0.997, 1.000)**	**0.010**	**0.998 (0.996, 1.000)**	**0.013**
Robustness (mm)	1.6 ± 0.2	1.5 ± 0.2	**0.007 (0.000, 0.214)**	**0.004**	**0.003 (0.000, 0.208)**	**0.007**

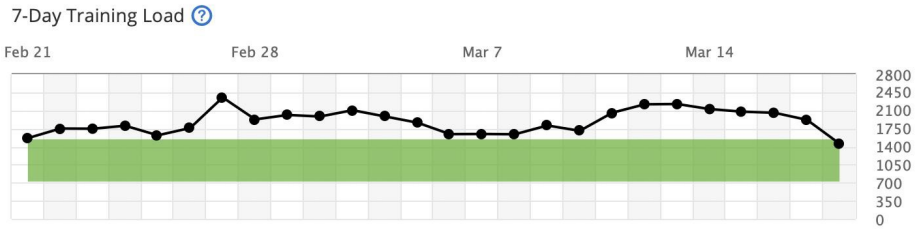
*Adjusted for sex, age, BMI

Koltun et al., Frontiers in Physiology, 2022

Wearables: Garmin Instinct Watch

- Wireless communication
- Solar powered
- Access to global navigation satellite systems.
- Wrist-based heart rate and Pulse Ox^2 sensor
- Track training load
- Export data into customized .CSV file





Time Period	Activities	Total Distance	Total Activity Time	Moving Time	Activity Calories	Total Elev Gain	Average Speed	Average Heart Rate	Average Run Cadence
03/14/2021	8	31.06 mi	7:23:47 h:m:s	6:03:42 h:m:s	3,386 C	1,220 ft	4.2 mph	126 bpm	187 spm
03/07/2021	12	61.39 mi	12:27:56 h:m:s	10:39:59 h:m:s	6,151 C	2,227 ft	4.9 mph	138 bpm	185 spm
02/28/2021	15	61.75 mi	13:44:12 h:m:s	11:02:24 h:m:s	6,465 C	1,765 ft	4.5 mph	131 bpm	165 spm
02/21/2021	16	61.60 mi	13:18:00 h:m:s	9:39:39 h:m:s	6,877 C	2,642 ft	4.6 mph	132 bpm	134 spm
02/14/2021	7	19.68 mi	5:05:42 h:m:s	3:54:22 h:m:s	2,535 C	1,221 ft	3.9 mph	132 bpm	139 spm
Summary	**58**	**235.48 mi**	**51:59:37 h:m:s**	**403,886 h:m:s**	**25,414 C**	**9,075 ft**	**4.4 mph**	**132 bpm**	**162 spm**

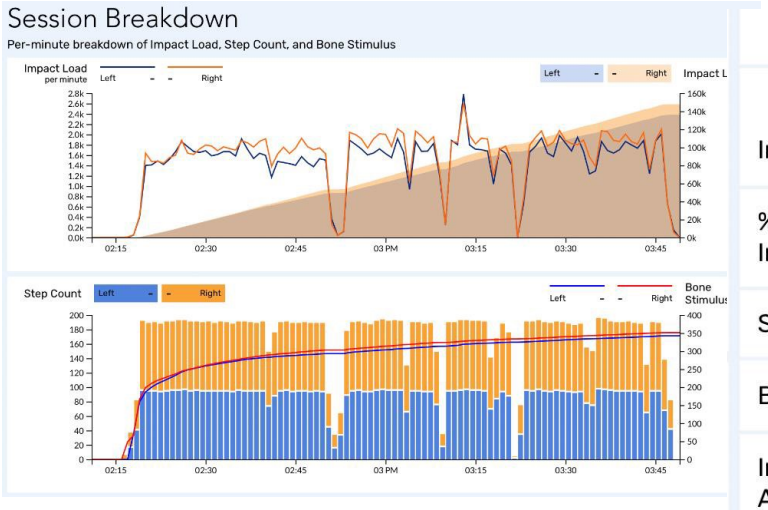
Wearables: ActiGraph Activity Monitor

- **Daily activity profile:** Steps, kcals, activity counts
- **Activity bouts:** Custom-defined bouts of sustained physical activity
- **Activity intensity:** Time spent within different intensity categories
- **Sleep score:** Total sleep time, wake after sleep onset, sleep efficiency.
- **Wear compliance:** Amount and percentage subject wore monitor.

- Wireless communication
- 180 days of storage
- 25-day battery life
- Worn on wrist, waist, ankle or thigh

Wearables: iMeasureU
Tibial Inertial Measurement Units (IMU)

- Wireless communication
- 12-hour battery life
- 1GB of storage
- Tri-axial accelerations



Summary

	Left	Right
Impact Load	136.1k	147.9k
% Session Impact Load	100%	100%
Step Count	7835	7844
Bone Stimulus	342.42	351.3
Impact Asymmetry	4.11% (R)	
Step Count by Intensity	L: 532	M: 11878	H: 3269

Impact Load: the sum of each intensity created from every impact propagated into the lower limbs.

Bone stimulus: an estimate of the mechanical stimulus (tibial shock) that would cause the bone to respond and remodel.

Impact asymmetry: between-limb difference in mean average impact intensity.

Longitudinal change: Track task and limb-specific load and changes in asymmetry.

IMeasureU

MSKI Risk Associations – A novel approach

- The human organism is a dynamic and non-linear system. Stern et. al. 2019
- The analytical methodologies chosen need to adequately identify the relevant information and complex relationships associated with MSKI.
  - "Web of determinants" Bittencourt et. al. 2016

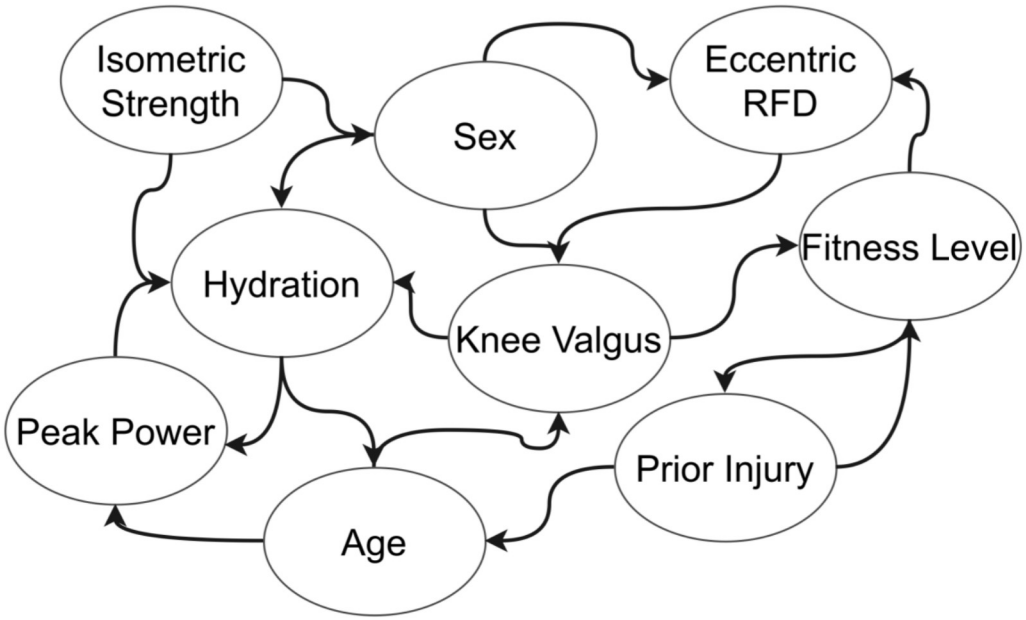


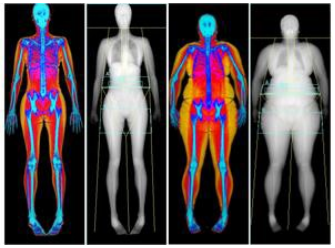
Figure produced in Draw.io

Comprehensive Human Performance Screening Battery (*CHPSB*)

Strength/Power (kinetics)

- Isometric Mid-thigh Pull
- VALD Force Frame
- Force Plate Testing
  - Vertical Jump

Body Composition/Bone Density



- DXA, HR-pQCT
  - Bone, fat, and muscle mass

Movement (kinematics)

- DARI Marker less Motion Capture
  - Range of movements (i.e., Squat, jumps, lunges)

Biomarkers

- Blood & Saliva
  - Bone Health, stress, immune

Aerobic Fitness

- VO2 testing
  - Aerobic and anaerobic threshold testing

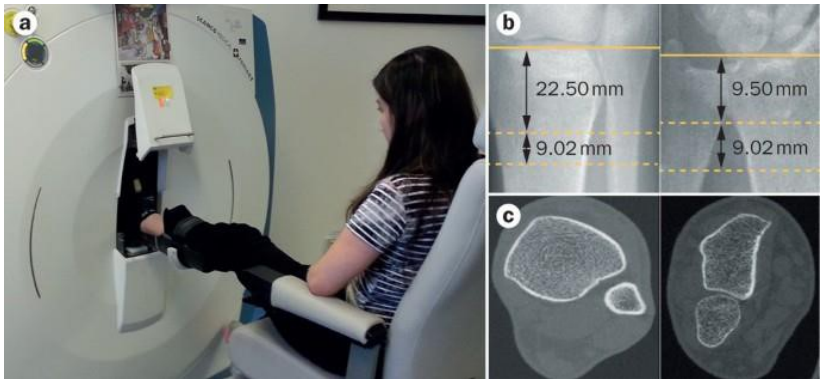
Questionnaires

REDCap™

- Injury type, location, mechanism
- Injury history
- Activity habits

NMRL Mobile Van capabilities

Bone Density: HR-pQCT

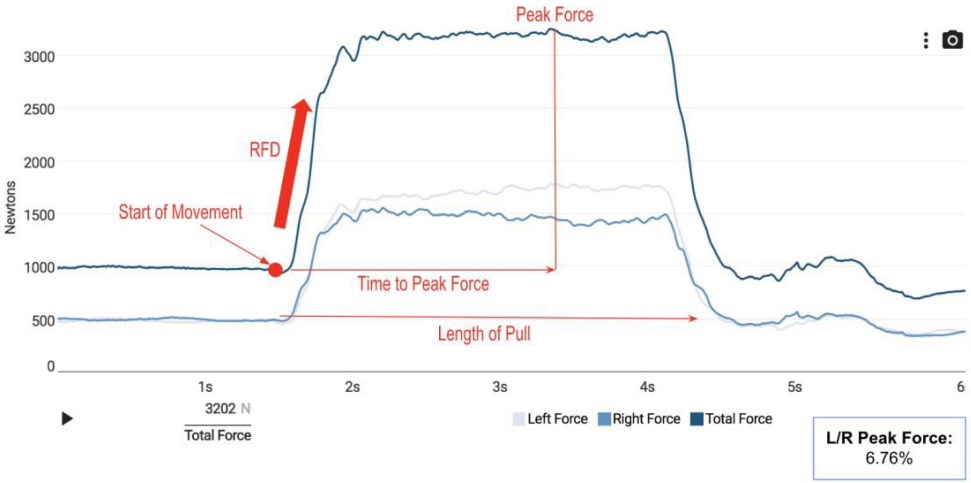


- Bone mineral density
- Structure
- Cortical/Trabecular

Body Composition : DXA

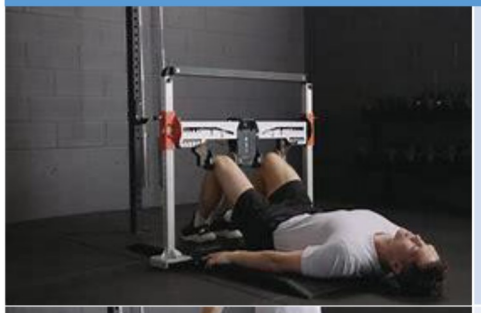
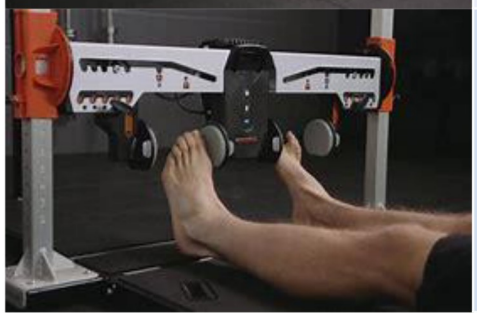
- Bone Density
- Body Fat %
- Muscle Mass
- Muscle Imbalances

Strength
Isometric mid thigh pull



- Maximal Isometric Force
- Rate of Force Development
- Asymmetries Between limbs

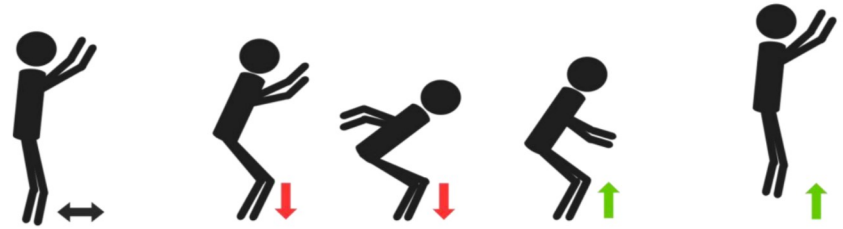
Strength
VALD Force Frame

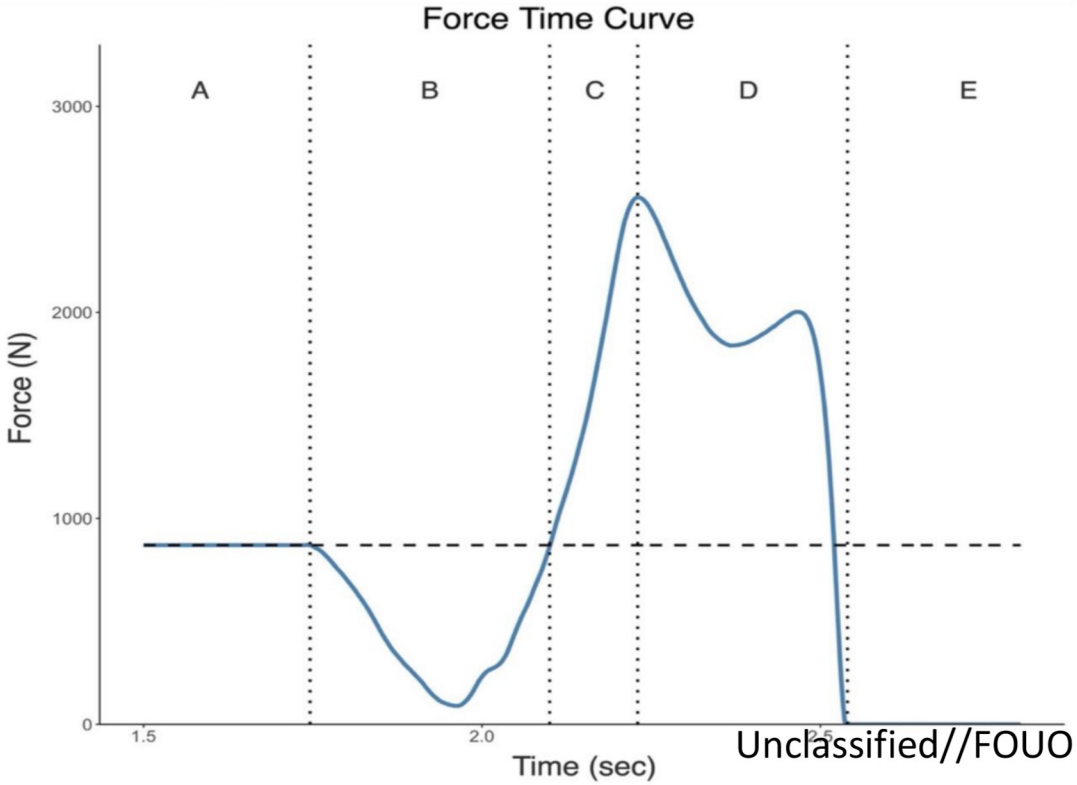
Lower Body Isometric Strength	
	Hip • Abduction/Adduction • Flexion/Extension • Internal/External Rotation
	Knee • Flexion/Extension
	Ankle • Inversion/Eversion

Maximal Strength

Strength Asymmetries

Power
Force Plates

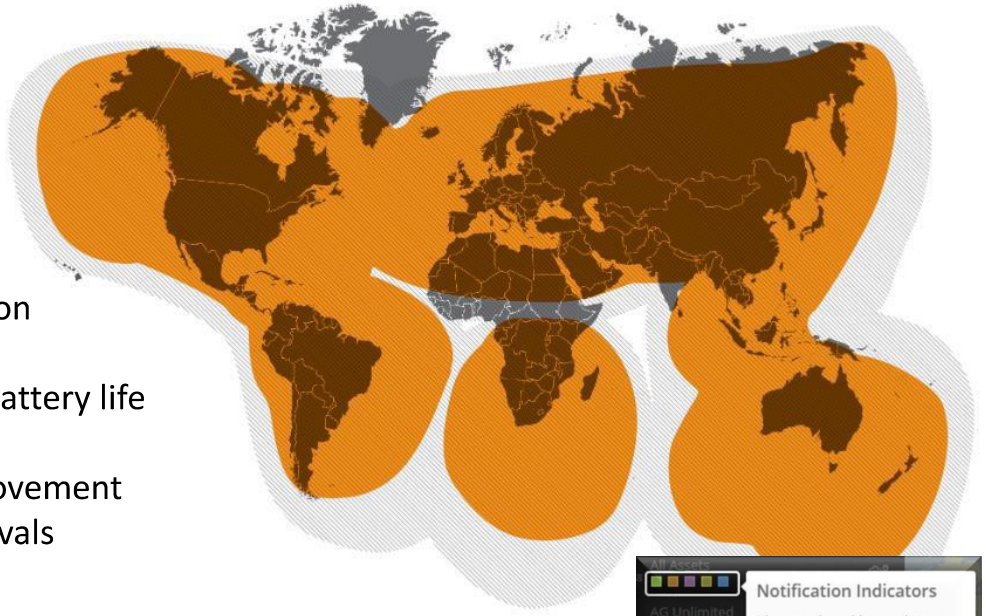


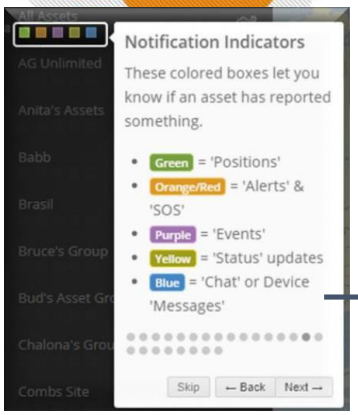


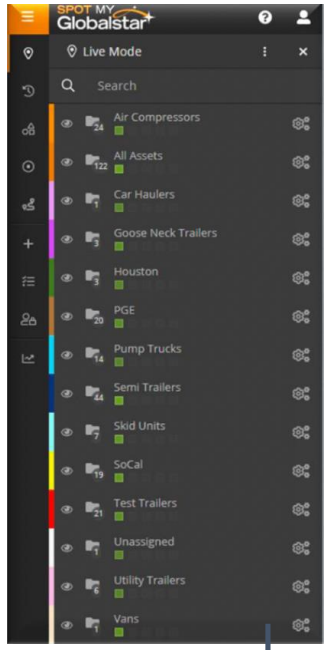
- Propulsive Force & Power
- Landing Force
- Rate of Force Development
- Impulse
- Jump Height
- Asymmetries

Wearables: SPOT Trace Satellite Tracker

- Wireless communication
- Max 45-day battery life
- 2.5-60min movement tracking intervals
- Status messages
- Live and historical tracking







Group assets and receive live notifications.

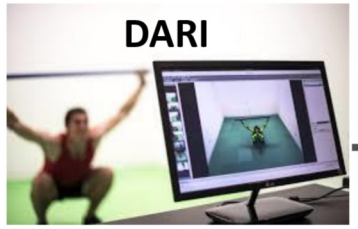
ŌURA Ring

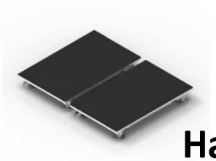
- Heart Rate
- Heart Rate Variability
- Respiration Rate
- Body Temperature
- Sleep

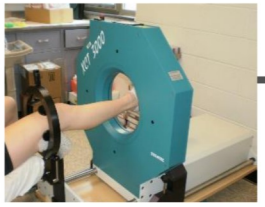
Next Steps: Serial Measures Salivary Biomarkers

- Investigate biomarkers associated with stress and immune function

Monitoring and Assessment Tools

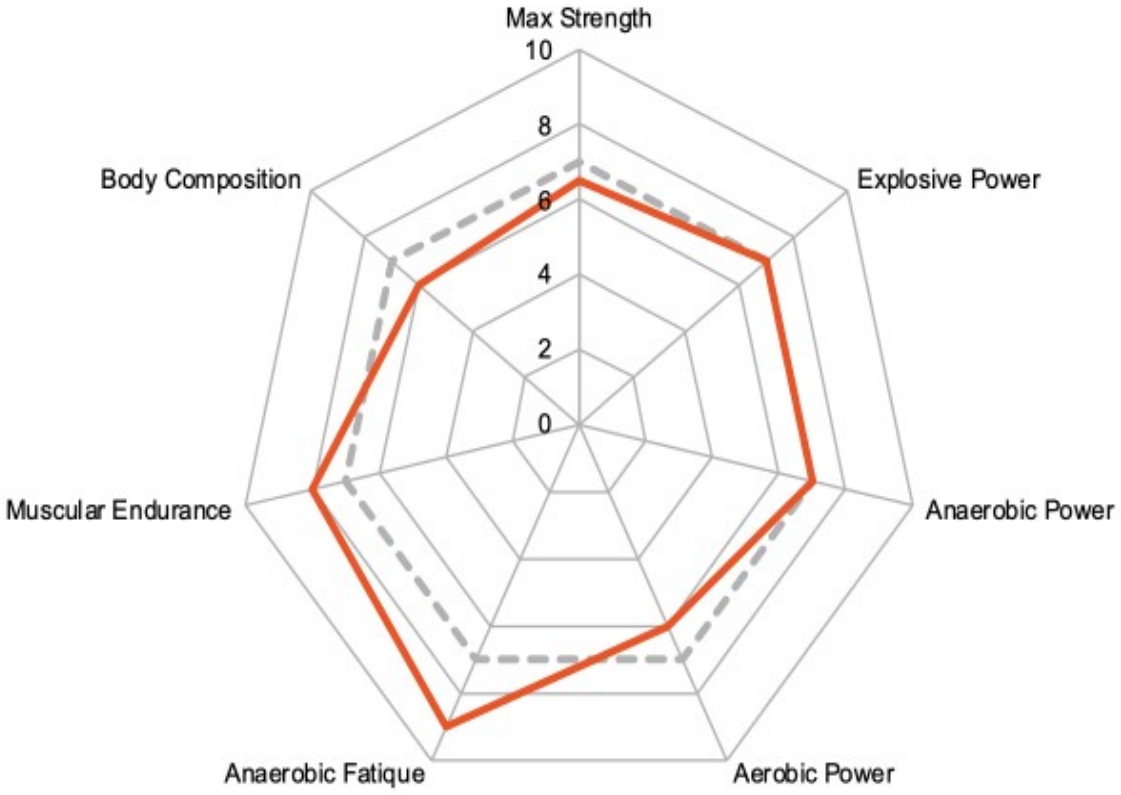






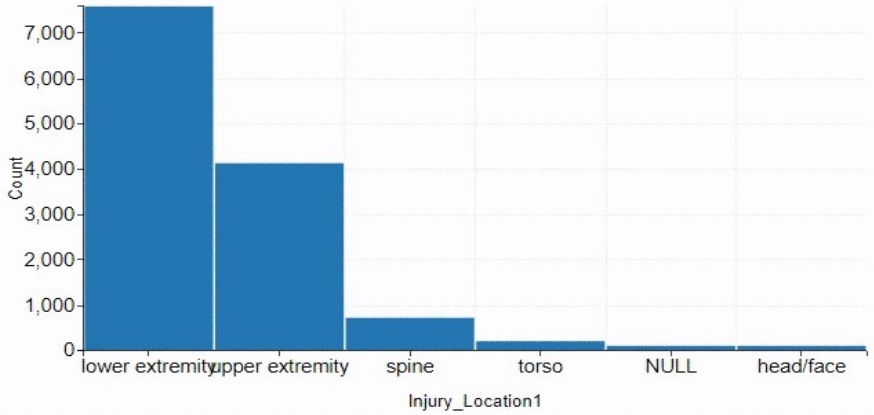
Comprehensive Human Performance Screening Battery (CHPSB)

- Evaluate MWTC Cadre through varying **physiological** biomechanical and biochemical **domains** for **evaluating physical readiness**.
- Evaluated periodically [6 months] for a comprehensive **individualized report** and **ranking across Cadre members.**



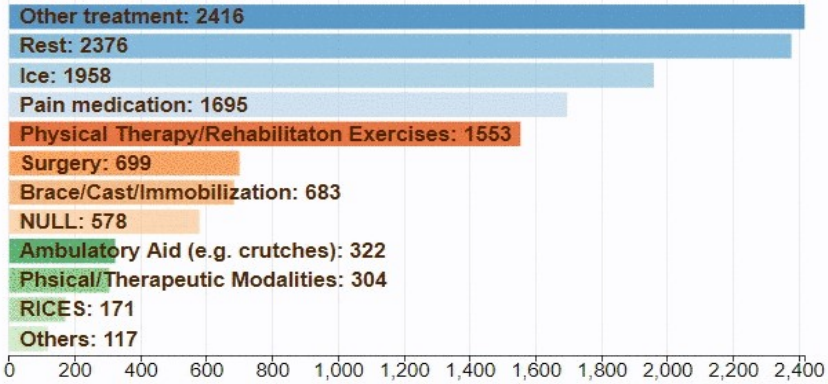
SPADE Data Load Dashboard Visualization + Add Chart + Add Static Content ✕ Reset All Filters Save Dashboard

Injury_Location1



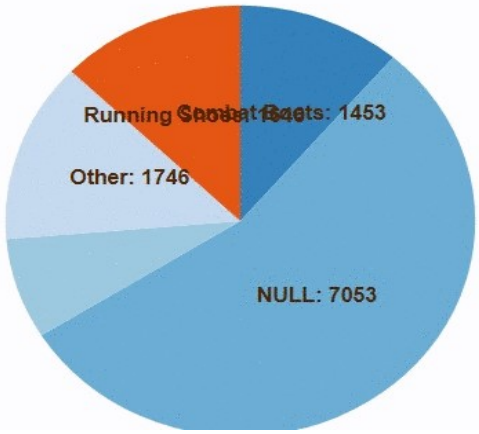
Reset Filter

Treatment

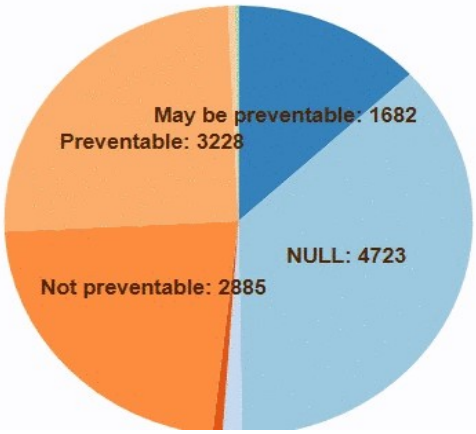


Reset Filter

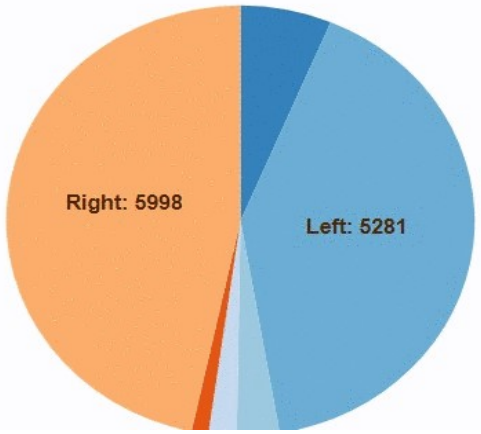
Footwear



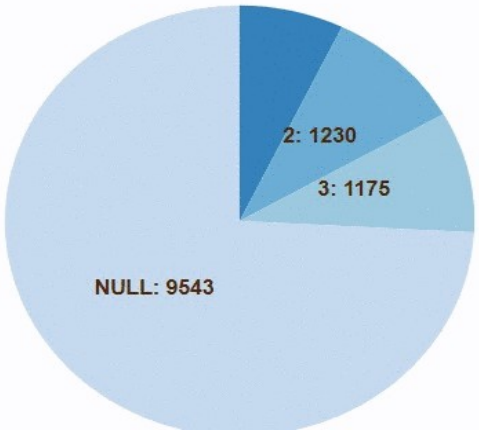
preventable



Injury_Side



Grade



Soldier Performance and Readiness as Tactical Athletes (SPARTA) Training Study

PHYSICAL TRAINING INTERVENTIONS

Strength and Power Focus
Predominance of 3-8RM range focused and power-based training

→ 12 weeks / 24 weeks +HIIT

Hybrid Group
intensities to target strength, power, hypertrophy, muscular endurance, isometric strength and stability

→ 12 weeks / 24 weeks +HIIT

Control Group
Continue with daily living activities

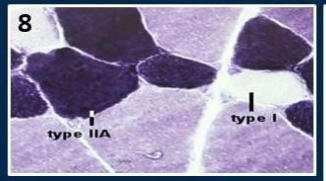
→ 24 weeks

STUDY OBJECTIVES

1. **Determine which physical training intervention(s) are most effective for improving military occupational performance with respect to women in Ground Close Combat roles**
2. **Establish the influence of different physical training intervention(s) on detraining in women**
3. **Examine mechanisms underpinning adaptations to different types of physical training**
4. **Compare sex-specific patterns of adaptation and detraining in response to different physical training interventions**

EXPERIMENTAL OUTCOMES

1. Strength Assessments
2. Tactical Athlete Monitoring System
3. Biomarkers
4. Physical Employment Standard Performance
5. Biomechanical Analysis
6. Neurocognitive Function
7. Maximal Aerobic Capacity
8. Muscle Biopsies
9. Load Carriage Training and Performance
10. Bone Health / Strength with High-Res pQCT



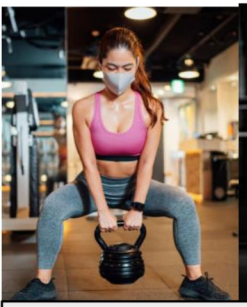
Bone and Body Composition Adaptations to Training (BoBCAT)

BC Nindl[1], JA Cauley[1], F Ambrosio[1], PK Fazeli[2], M Hubal[3], BJ Martin[1], MT Lovalekar[1], AJ Sterczala[1], SD Flanagan[1], KJ Koltun[1], CH Moon[2], H Iijima[1], JP Greeves[4], TJ O'Leary[4], SL Arana[4]

[1]University of Pittsburgh, Pittsburgh, PA, USA [2]University of Pittsburgh School of Medicine, University of Pittsburgh, Pittsburgh, PA, USA. [3]Indiana University-Purdue University, Indianapolis, IN, USA [4]Army Health and Performance Research, Army Headquarters, Andover, Hampshire, UK

Military personnel are exposed to unique physical demands in their training and operational environments that increase their risk of musculoskeletal injuries. Stress fractures are a common and costly injury in military populations, especially in initial entry training. Combatting the prevalence of stress fractures requires a better understanding of the mechanisms through which exercise influences bone and the optimal training parameters to maximize beneficial osteogenic adaptations.

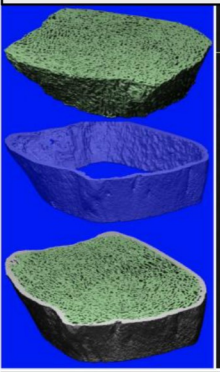
To do so, we aim to analyze training induced changes in bone density, geometry and strength as well as novel bone-muscle crosstalk factors, bone marrow adiposity, and extracellular vesicle (EV) cargo in a laboratory training group and a standard of care ROTC group. Additionally, we will compare the different exercise program parameters and training loads of Pitt athletic teams with changes in state of the science bone measures and body composition over the competitive season.



Lab-Based Training Groups

Three Rivers Battalion ROTC

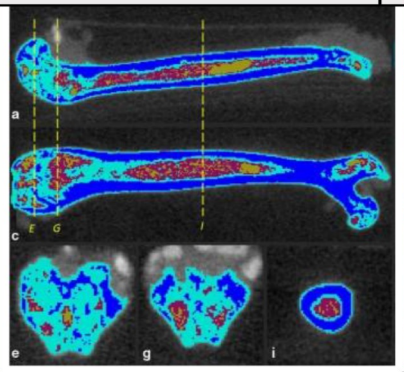
University of Pittsburgh Athletes



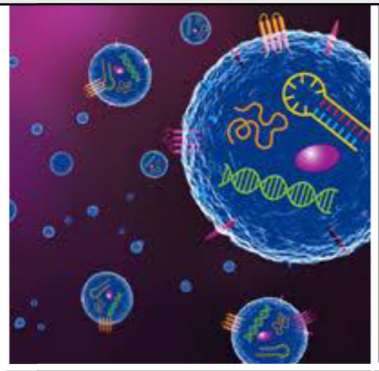
Bone Imaging

Bone Biomarkers

Load Tracking



Marrow Adiposity



EV miRNA

Body Comp.

NSCOR: NASA Specialized Center of Research

Biomarkers for adaptation and resilience in ICC/ICE environments

ICARUS (U Penn)

7-day isolation

HERA (NASA JSC)

45-day isolation

NEUMAYER (Antarctica)

15-month isolation

NEUROMUSCULAR RESEARCH LABORATORY
UNIVERSITY OF PITTSBURGH

Thank You.