US Army (ARL & NSRDEC) Approach to Assessment of Exoskeleton Systems

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ARL-NSRDEC Collaboration

Purpose: Begin to standardize (across the Army RDECOM) terminology, test methods and performance metrics to assess exoskeleton systems

Approach:

- Historically, vendor claims have driven evaluations
- Comprehensive system evaluation spreadsheet
- Jointly developing standardized testing methods/metrics to assess the effects of systems on Soldier physical performance and ensure data/findings compatibility.
- Engage broader community (Government, Industry, Academia)
- Produce public-releasable document *(in-progress)*

Payoff:

- Unified Army (and potentially broader adoption of) standards for assessment of systems designed to assist specific tasks
- Suite of testing methods and performance metrics that can be used by evaluators and/or developers of exoskeletons to best assess and benchmark as they mature

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Joint Actuation

Current Goal: Decreased muscular effort and metabolic cost through augmentation of mechanical work

- Target single or multiple joints
- Various actuation strategies
  - Mechanical actuator at joint
  - Cable driven
  - Hydraulic
  - Passive

Boston Dynamics/Ekso Bionics RheAct

ASU Hip Exo

Ekso Bionics/Lockheed HULC

Harvard/Wyss Soft Exosuit

Load Transfer / Redistribution

Current Goal: Mitigate physiologic effects of load carriage through modified load path

- Transfer to adjacent body segments or to ground
- Passive structures

Vertical Load Offset System (VLOS)

University of Delaware

Dynamic Weight Distribution

Assessment Design

Participants

- Infantry Soldiers or Soldiers with sufficient load carriage experience

Conditions

- Baseline (Soldier wearing standard equipment/load)
- Technology ON (in active state, worn in addition to Baseline configuration)
- Technology OFF (in passive/inactive state, worn in addition to Baseline configuration)

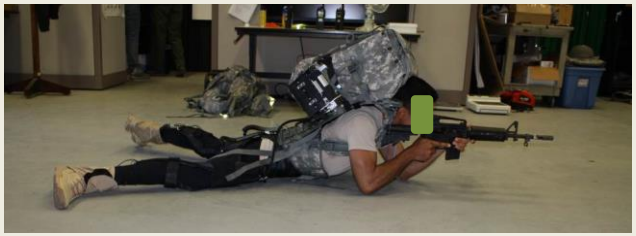
Worn/carried equipment

- Standard issue uniform (ACUs, boots)
- Protective equipment (helmet, ballistic vest)
- Load carriage equipment (assault pack, rucksack)
- Dummy weapon

Assessment Design

Tasks

- Static balance (effect on postural stability, indicator of fatigue)
- Functional range of motion (mobility restrictions)
- Basic motions (mobility restrictions, effects on task performance)
  - Sitting, crawling, squatting, side-stepping, taking a knee, stairs, ladder climb, bend and pick up object, etc.
- Dynamic motions (mobility restrictions, effects on task performance)
  - Drop landing, run and cut
- Movement between firing positions (equipment compatibility, effects on task performance)



Assessment Design

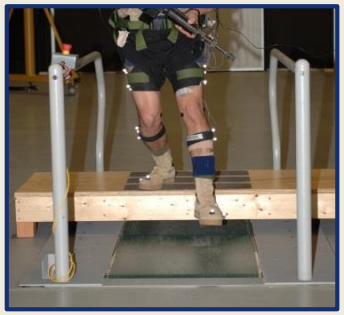
Tasks (cont.)

- Treadmill walking/jogging (effects on gait under controlled conditions)
- Road march/cross-country walking (effects on gait over natural terrain)

Assessment Design

Tasks (cont.)

- Stepping up/down and over (effects on obstacle negotiation in controlled environment)
- Obstacle course (effects on obstacle negotiation under operational conditions)
- Vertical jump (effects on dynamic movement, indicator of fatigue)
- Marksmanship (effect on operational task)



Tools & Metrics

Biomechanics

Stability - Effects on balance & movement efficiency, may indicate fatigue

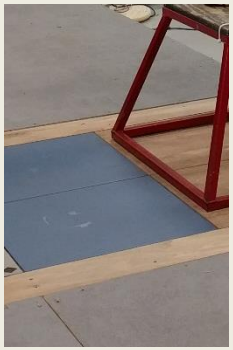
- Dynamic postural stability index (DPSI)
- Standard deviation of ground reaction forces
- Step width variability
- IMU-based metrics

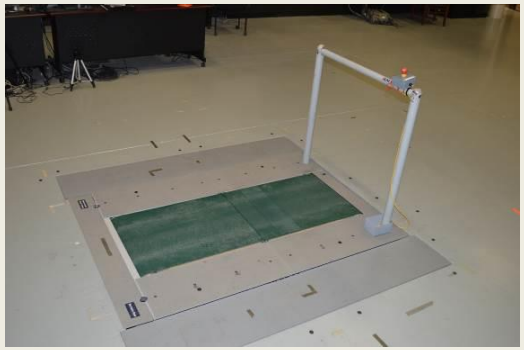
Inertial measurement unit (IMU)
(stability, kinematics)

Spatiotemporal - effects on natural gait

- Speed
- Cadence
- Step/stride time/length/width

Optogait (spatiotemporal)





In ground force plates or instrumented treadmill
(stability, spatiotemporal, kinetics)

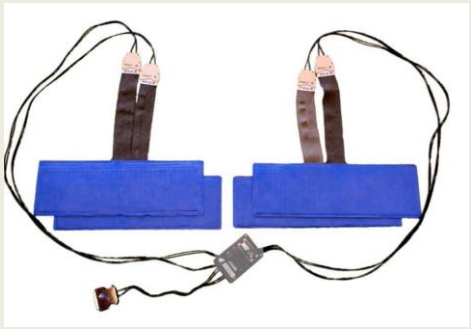
Biomechanics (cont.)

Kinematics - Effects on natural gait & mobility, may indicate injury risk

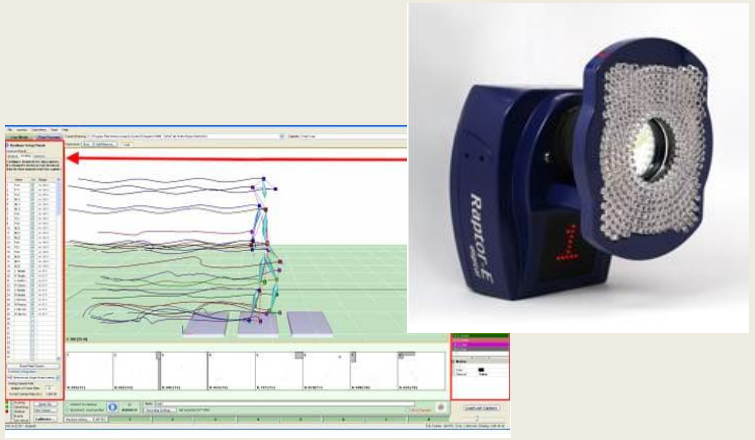
- Peak joint angles
- Range of motion

Kinetics - Effects on natural gait & MSK loading, may indicate injury risk

- Peak ground reaction forces
- Loading rates
- Joint moments/powers



Pliance Pressure Sensors (novel).
(kinetics)



optical motion capture
(kinematics)

Tools & Metrics

Physiologic

Cardiopulmonary - Physiologic workload & energy usage

- Heart rate
- Rate of oxygen consumption / total kilocalories expended
- Cost of transport
- Respiratory exchange ratio

Cardiopulmonary testing system
(cardiopulmonary)

Muscle Function - Muscular work & fatigue

- Peak/average/integrated muscle activity
- Muscle activity median frequency
- Vertical jump height
- Muscular force/torque/work

Electromyography (EMG) system
(muscle function)

Biodex
(muscle function)

Tools & Metrics

Physiologic (cont.)

Subjective Ratings – Effort & comfort

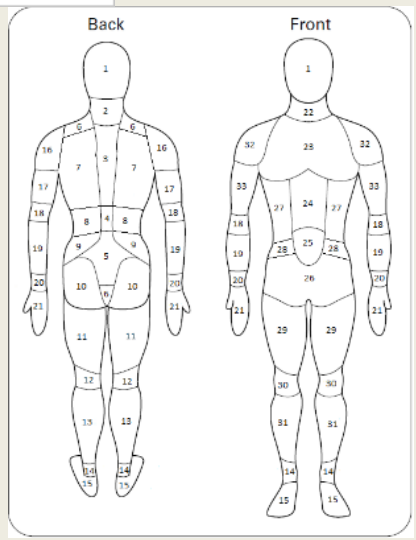
- Ratings of perceived exertion (RPE)
- Ratings of pain, soreness, discomfort (PSD)

Skin/core Temperature – Heat stress

Blood Lactate – Exercise intensity & recovery

CorTemp system
(core temperature)

6	No exertion
7	
8	
9	
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Very hard
18	
19	
20	Maximal exertion



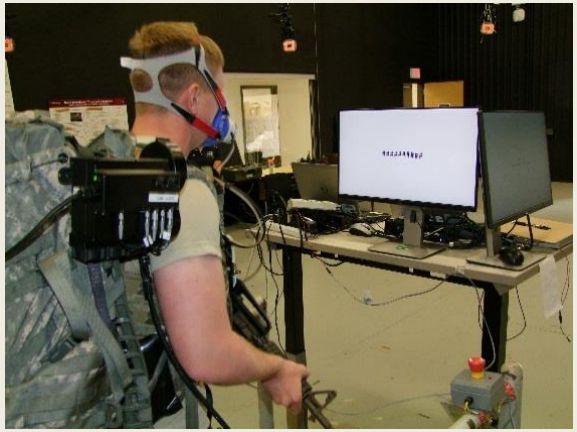
Borg scale & custom PSD questionnaire
(subjective ratings)

Tools & Metrics

Cognitive

Go/No-Go task – Response inhibition, short-term memory

- Response time
- Errors of omission/commission
- Word recall



Operational

Mobility Performance

- Time to complete/average speed
- Quality of movement

Marksmanship

- Shot timing, accuracy, and dispersion

Human Factors Considerations

Ease of Use

- Ability to don, adjust, and doff device quickly, easily and ideally by user
- User interface is easy to use and intuitive

Fit & Adjustability

- Fits the Soldier/user population (males/females, tall/short, large/small)
- Has adjustability to accommodate ranges of body dimensions
- Does not restrict normal body range of motion

Compatibility with Soldier Gear

- Military protective clothing & equipment (e.g., body armor, CB protection, eyewear)
- Load carriage equipment
- Vehicle/aircraft (e.g., ingress/egress and sit comfortably, reach controls)
- Interference (i.e., EMI) that may impede the use of electronics
- Ability to don/doff load carried while wearing device

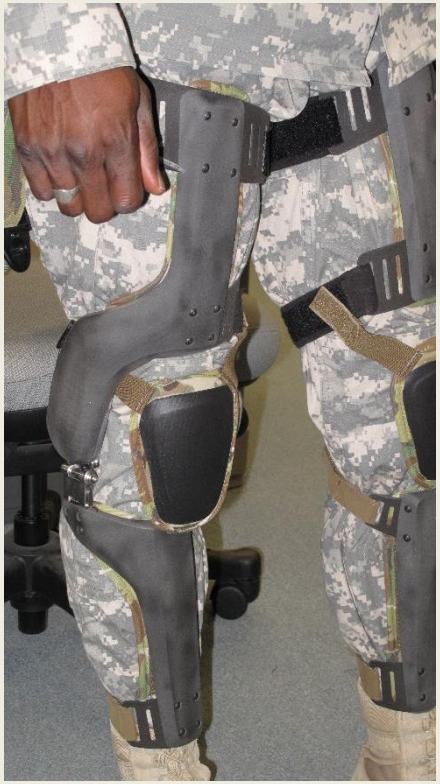
Ability to Perform Military Movements

- Basic movements: sit, stand, high step, squat, bend at waist, take a knee, aim a weapon (prone, kneeling, standing), stairs, jog, sprint, walk at inclines, etc.

Human Factors Considerations

Comfort, Safety, Health Hazards & Survivability Issues

- Chafing, hot spots, bruising, pressure, etc. are not created
- Device safety mechanisms are incorporated to ensure joints are not extended beyond their normal range of motion
- Snag hazards are removed
- If the device stops working (either via damage, mechanical failure, or lack of power), how does the device respond? What requirements are placed on the user?
  - Recommend including a fail-safe mode automatically activated in the event of power failure or other device malfunction such that the weight of the device and load attached to it is not transferred to the user in a harmful way
- Device does not substantially increase the user's thermal burden or perceived effort



Operational Use

- Training and tools needed to maintain/adjust device
- Storage of device and other unique aspects of device
- Device must operate under rugged conditions (e.g., sand, water, dust, extreme environments, etc.)
- Intended uses/tasks/user groups
- Does clothing/existing equipment need to be modified for use

Human factors

Subjective ratings – Questionnaires, interviews, personal communications

Observations – Ease of use, safety/health hazards, impacts on movement/ mission performance, compatibility with Soldier equipment & tasks

Timed Performance – Time to don, doff, adjust or perform mission activity

Obstacle/Mobility Courses – Assess device impacts on movement and physical performance

Marksmanship Simulator or Live Fire – Assess device impact on marksmanship (e.g., timing, accuracy, and precision)

Standardized Test Methodologies – Execution of standard tests (NIST, ASTM, NFPA, occupational tests), while less mission specific, show impacts in performance compared to population norms (dexterity/tactility, vision, range of motion, etc.)