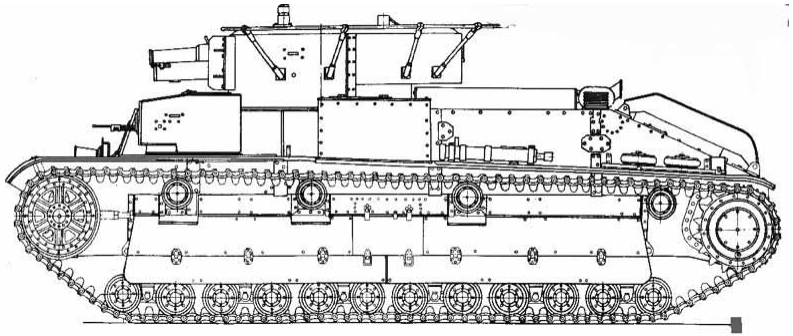
Enhanced Technologies for Optimization of Warfighter Load

(ETOWL)

- Background
- SANTOS-ETOWL
- Method: Predictive Dynamics
- SANTOS-ETOWL Software Demonstration

By: The Virtual Soldier Research
THE UNIVERSITY OF IOWA

Why Human Simulation



Physical prototypes

Engineering Analysis

Stress tests
Vibration
Sound
Dynamics analysis (motion)
Aerodynamics
Thermal analysis
Fluid analysis

Human Systems Integration
Human Performance

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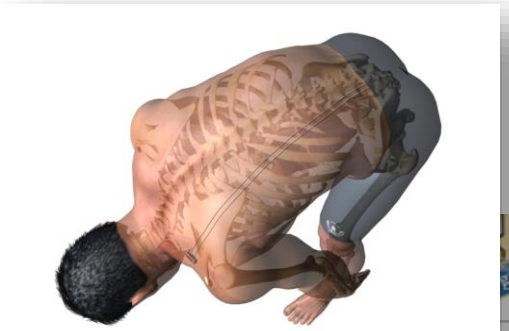
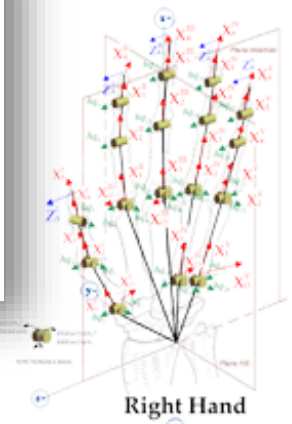
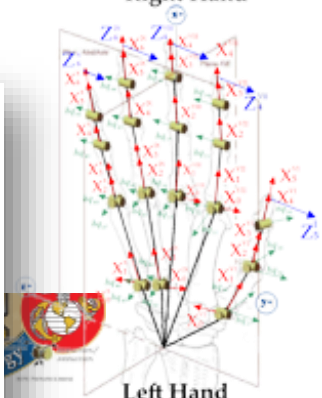
Realistic

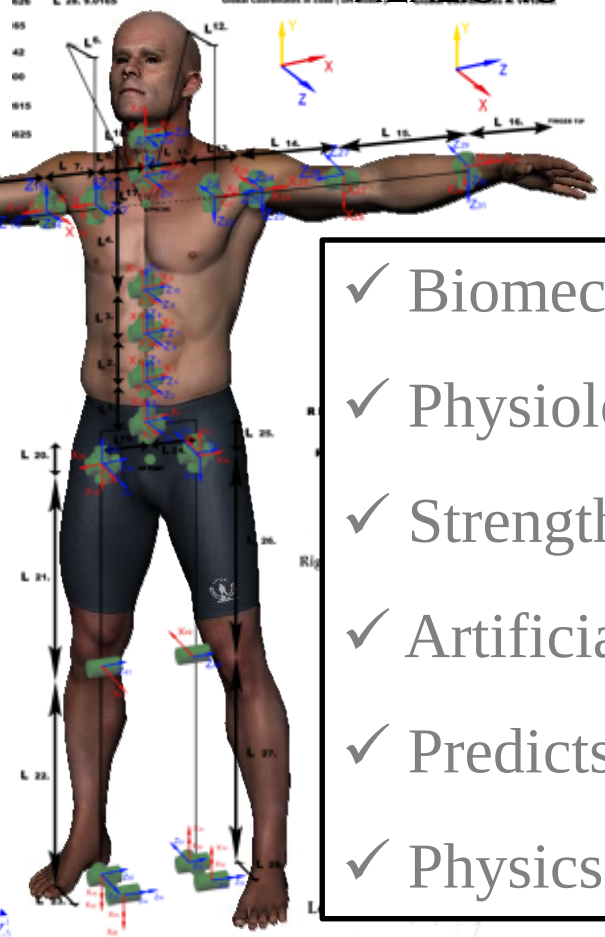




Right Hand



Left Hand

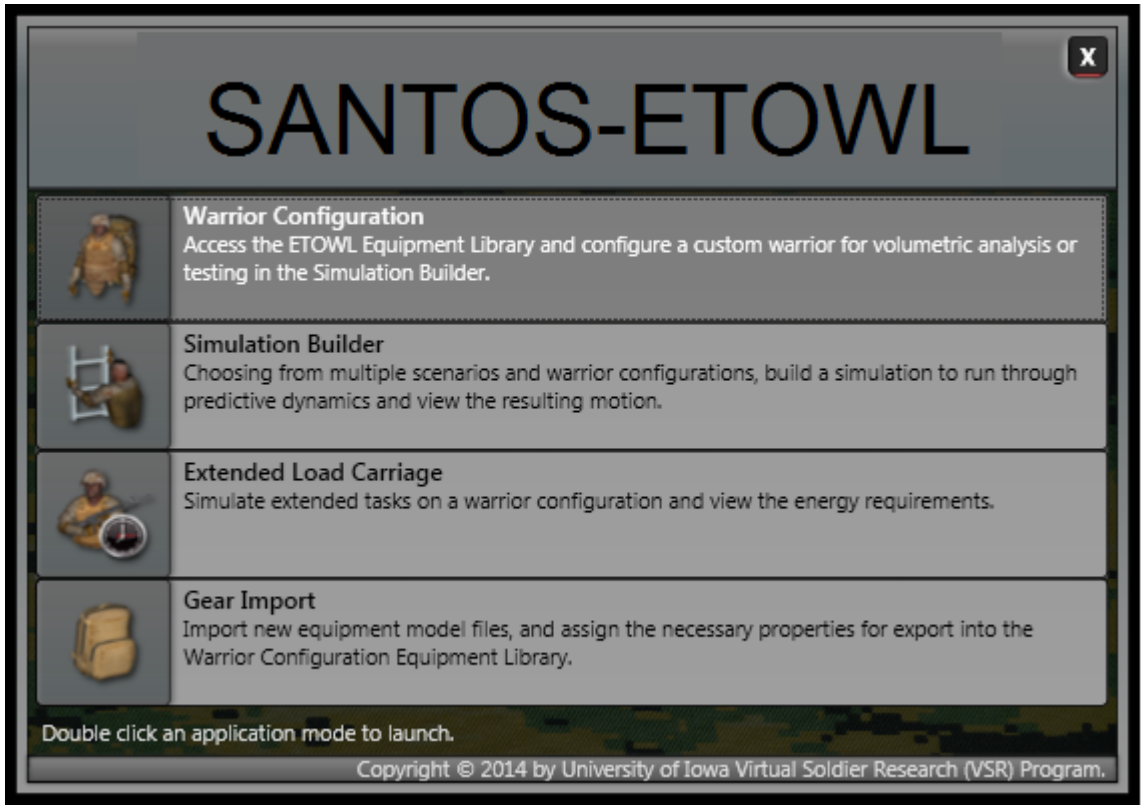


- ✓ Biomechanics
- ✓ Physiological modeling
- ✓ Strength & Fatigue
- ✓ Artificial intelligence
- ✓ Predicts behavior
- ✓ Physics-based

ETOWL

A human Simulator

- Conduct trade off analysis
- Assess Marine performance
- Evaluate gear prior to procurement



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GruntSim male Marines

***Santos**, 220 Male, 508 Male, 530 Male, 601 Male, 1719 Male, 1953 Male, 2033 Male, 2459 Male.*

- Anthropometry
- Weight
- Body type
- Strength

Male Avatar Statistics			
Avatars	Height	Weight	Strength Percentile
Santos	6 ft. 1 in	173.72 lbs.	90 %
220 Male	5 ft. 7 in	160.94 lbs.	80 %
508 Male	5 ft. 7 in	143.52 lbs.	75%
530 Male	6 ft. 3 in	244.93 lbs.	90%
601 Male	6 ft. 2 in	155.43 lbs.	80%
1719 Male	5 ft. 11 in	177.91 lbs.	85%
1953 Male	5 ft. 7 in	195.11 lbs.	80%
2033 Male	6 ft. 3 in	217.82 lbs.	90%
2459 Male	5 ft. 4 in	122.14 lbs.	75%

GruntSim female Marines

Sophia, *0752 Female, 1806 Female, 2096 Female, 2316 Female, 2324 Female, 2531 Female, 2563 Female.*

Female Avatar Statistics			
Avatars	Height	Weight	Strength Percentile
Sophia	5 ft. 6 in	133.00 lbs.	80%
0752 Female	5 ft. 10 in	139.33 lbs.	80%
1806 Female	5 ft. 9 in	164.91 lbs.	85%
2096 Female	5 ft. 3 in	121.92 lbs.	75%
2316 Female	5 ft. 7 in	156.75 lbs.	90%
2324 Female	5 ft. 6 in	158.29 lbs.	90%
2531 Female	5 ft. 0 in	129.19 lbs.	85%
2563 Female	5 ft. 3 in	119.93 lbs.	75%

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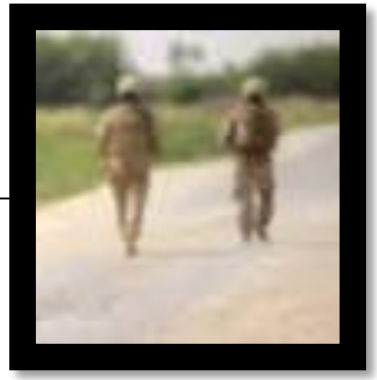
ETOWL … is a platform

Warrior Configuration

Simulation Builder

Gear Import

Extended Load Carriage



Predicting Human Motion

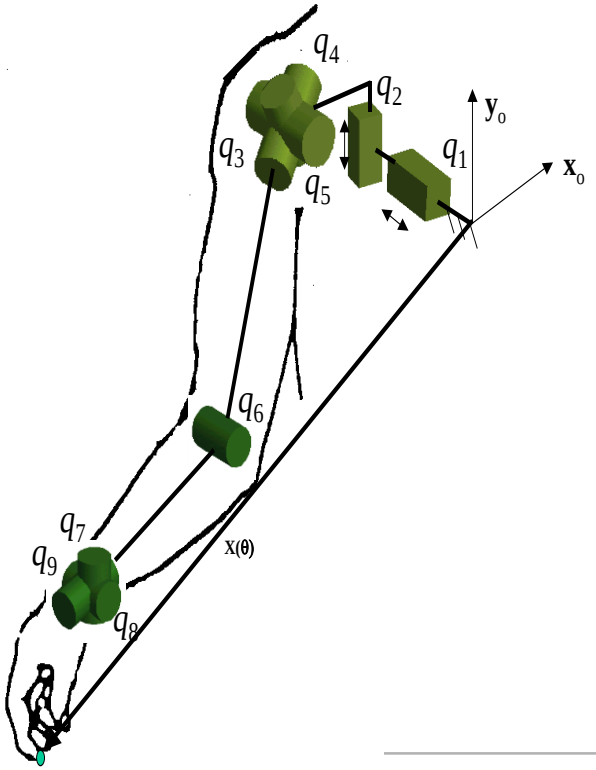
In 2004…

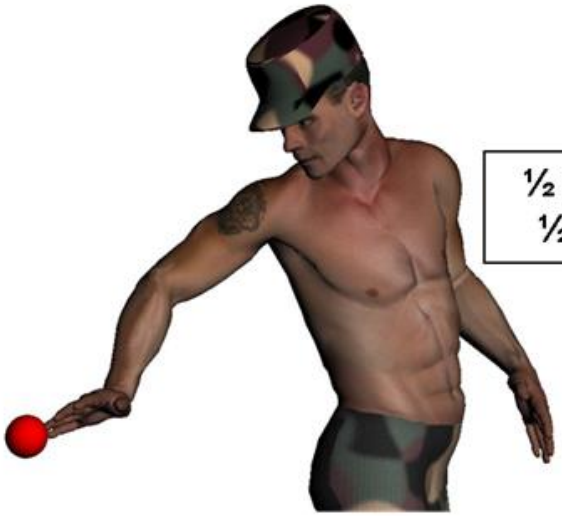
Objective:
Minimize function

Find:
Joint angles

Constraints:
Joint range of motion

Joint Displacement only

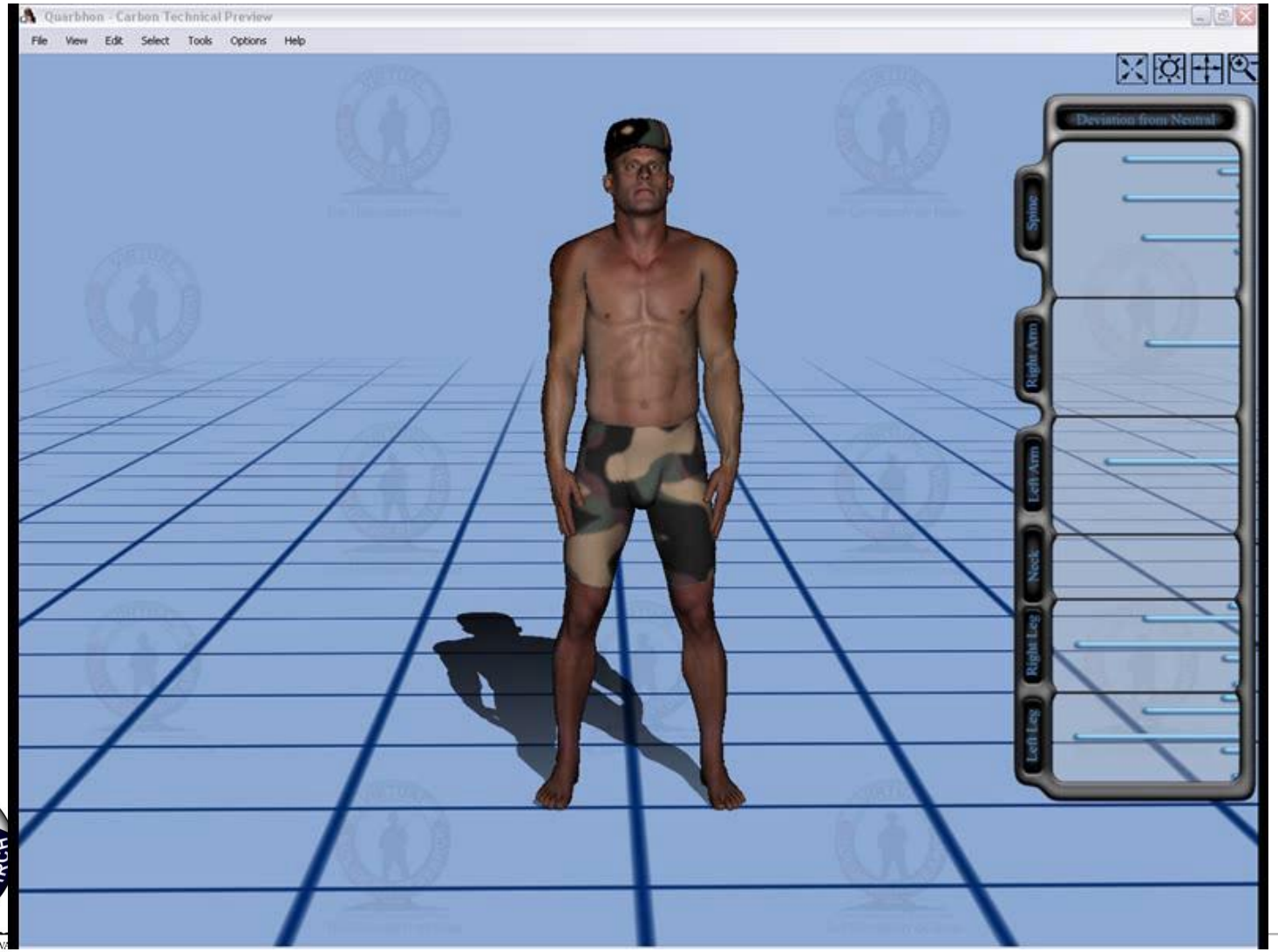




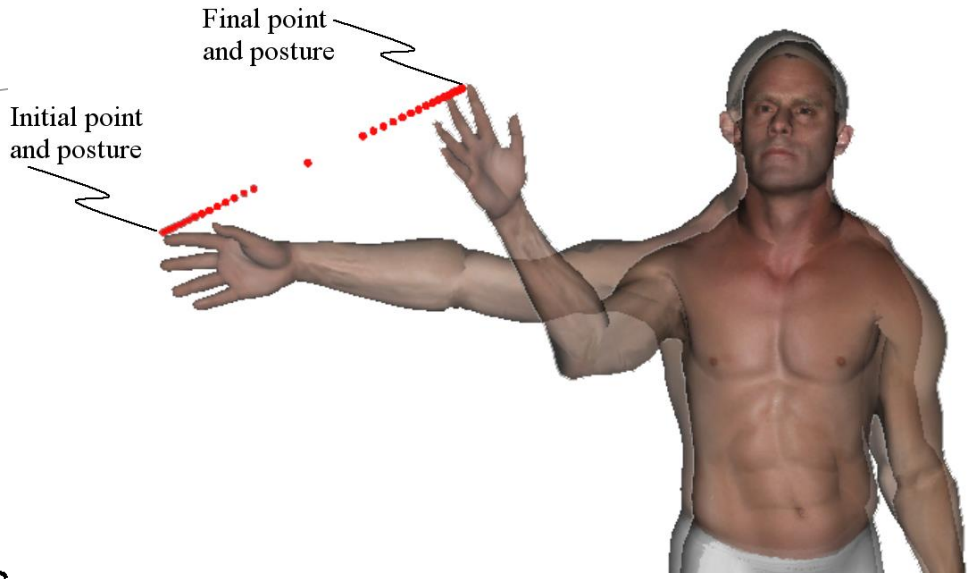
½ Visual Displacement
½ Joint Displacement

In 2004/2005

https://youtu.be/Zwj6evMMQ0Q

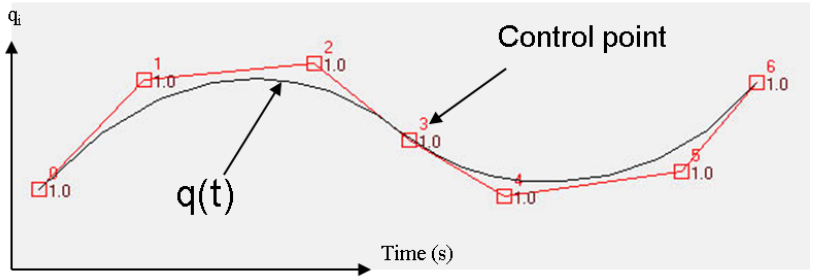


Motion Prediction



Formulation

Find: control points for B-spline curves



To optimize:

Human performance measure(s)

Subject to:

1) Follow path
2) Stay within ROM
3) Avoid collisions

In 2005/2006

https://youtu.be/JkXNVwzq-8Q

Predictive Dynamics

Significant Development
Predictive Dynamics

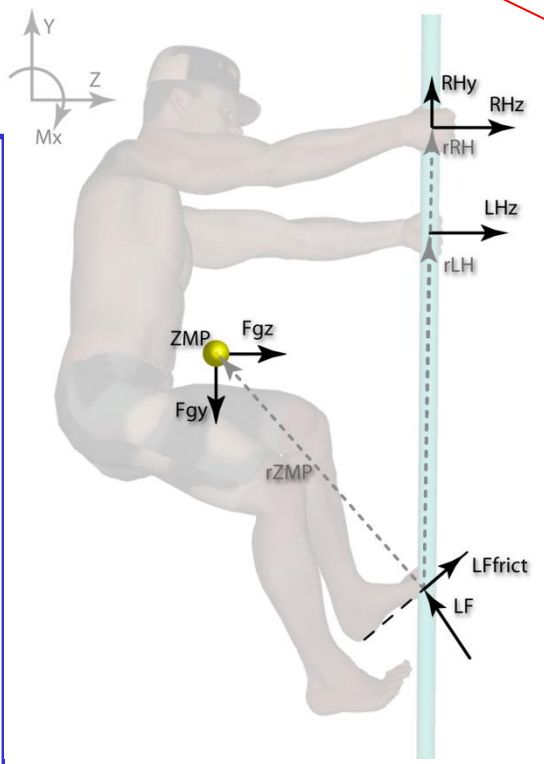
- Physics based

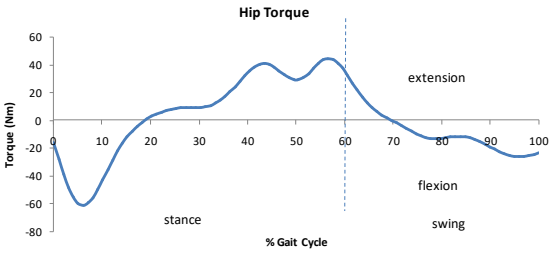
- Predictive: cause and effect

Objective:
Execute a task

Find: Joint angles, Torques

Constraints:
- Range of motion
- Distance to target
- Strength constraints
-
- Laws of Motion





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Laws of Motion

$$\boldsymbol{\tau} = \underbrace{\mathbf{M}(\mathbf{q})\ \ddot{\mathbf{q}}}_{\substack{mass\&inertia\\ matrix}} + \underbrace{\mathbf{V}(\mathbf{q},\dot{\mathbf{q}})}_{\substack{Coriolis\&\\ Centrifugal}} + \underbrace{\sum_i \mathbf{J}_i^{\mathrm{T}} m_i \mathbf{g}}_{gravity-forces} + \underbrace{\sum_k \mathbf{J}_k^{\mathrm{T}} \mathbf{F}_k}_{external-forces} + \underbrace{\mathbf{K}\left(\mathbf{q}-\mathbf{q}^N\right)}_{muscle-elasticity}$$

$$J_1\left(q,\ \tau,\ t\right) = \int_{t=0}^{T} \tau \cdot \tau\ dt$$

$$s.t.: \quad s^{\tau}\boldsymbol{\tau}_h - \boldsymbol{f}\left(s^q\mathbf{q}_h, s^q\dot{\mathbf{q}}_h, s^q\ddot{\mathbf{q}}_h, s^t\mathbf{t}_h\right) = \mathbf{0}$$

$$\mathbf{g}(\Upsilon_h) \le \mathbf{0}$$

$$s^q\mathbf{q}^L \le s^q\mathbf{q}_h \le s^q\mathbf{q}^U$$

$$s^{\tau}\boldsymbol{\tau}^L \le s^{\tau}\boldsymbol{\tau}_h \le s^{\tau}\boldsymbol{\tau}^U$$

Statics versus Dynamics

$$\tau = \underbrace{M(q)\ \ddot{q}}_{\text{mass\&inertia matrix}} + \underbrace{V(q,\dot{q})}_{\text{Coriolis\& Centrifugal}} + \underbrace{\sum_i J_i^{T} m_i g}_{\text{gravity-forces}} + \underbrace{\sum_k J_k^{T} F_k}_{\text{external-forces}} + \underbrace{K\left(q - q^{N}\right)}_{\text{muscle-elasticity}}$$

Statics versus Dynamics

[redacted]

$$\boldsymbol{\tau} = \underbrace{\mathbf{M}(\mathbf{q})\,\ddot{\mathbf{q}}}_{\substack{mass\&inertia\\matrix}} + \underbrace{\mathbf{V}(\mathbf{q},\dot{\mathbf{q}})}_{\substack{Coriolis\&\\Centrifugal}} + \underbrace{\sum_i \mathbf{J}_i{}^{\mathbf{T}} m_i \mathbf{g}}_{gravity-forces} + \underbrace{\sum_k \mathbf{J}_k{}^{\mathbf{T}} \mathbf{F}_k}_{external-forces} + \underbrace{\mathbf{K}\left(\mathbf{q}-\mathbf{q}^N\right)}_{muscle-elasticity}$$

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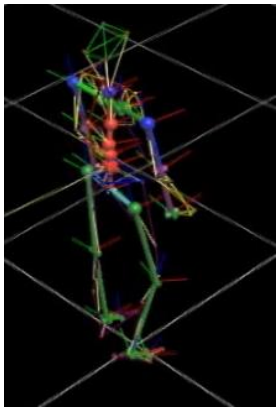
Predictive Dynamics

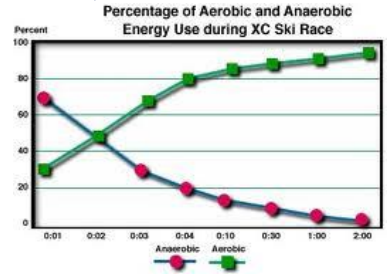
Understand the task

Obtain expert advice

Obtain Motion Capture



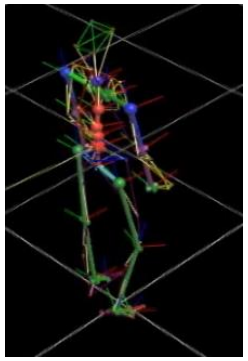
Formulate tracking



Obtain energy and physiology data

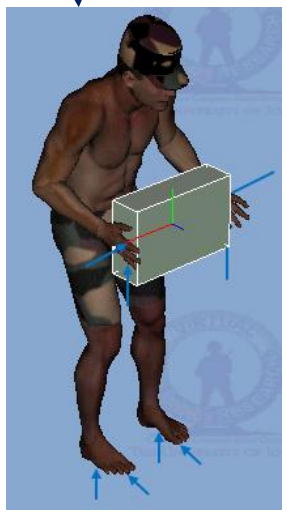
Formulation

Understand contact points



Define contact duration

Amend formulation with constraints



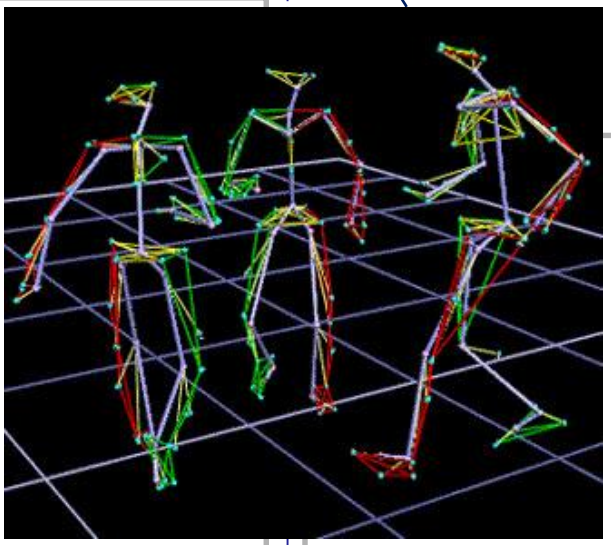
Determine cost functions

Derive gradients for optimization

Experiments & Validation

PD Simulation

IRB



Validation

Determinants of motion

Refine formulation based on validation feedback

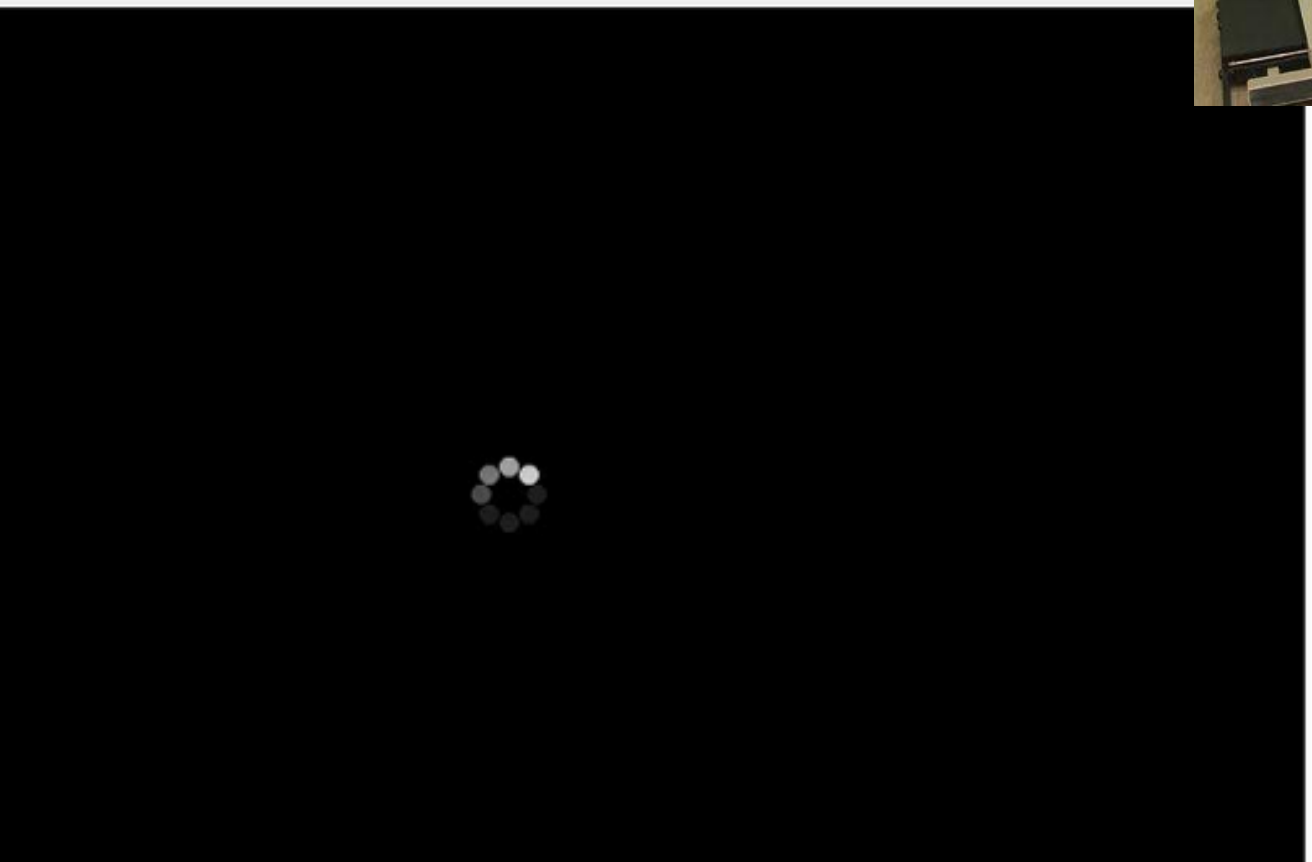
Cause & Effect

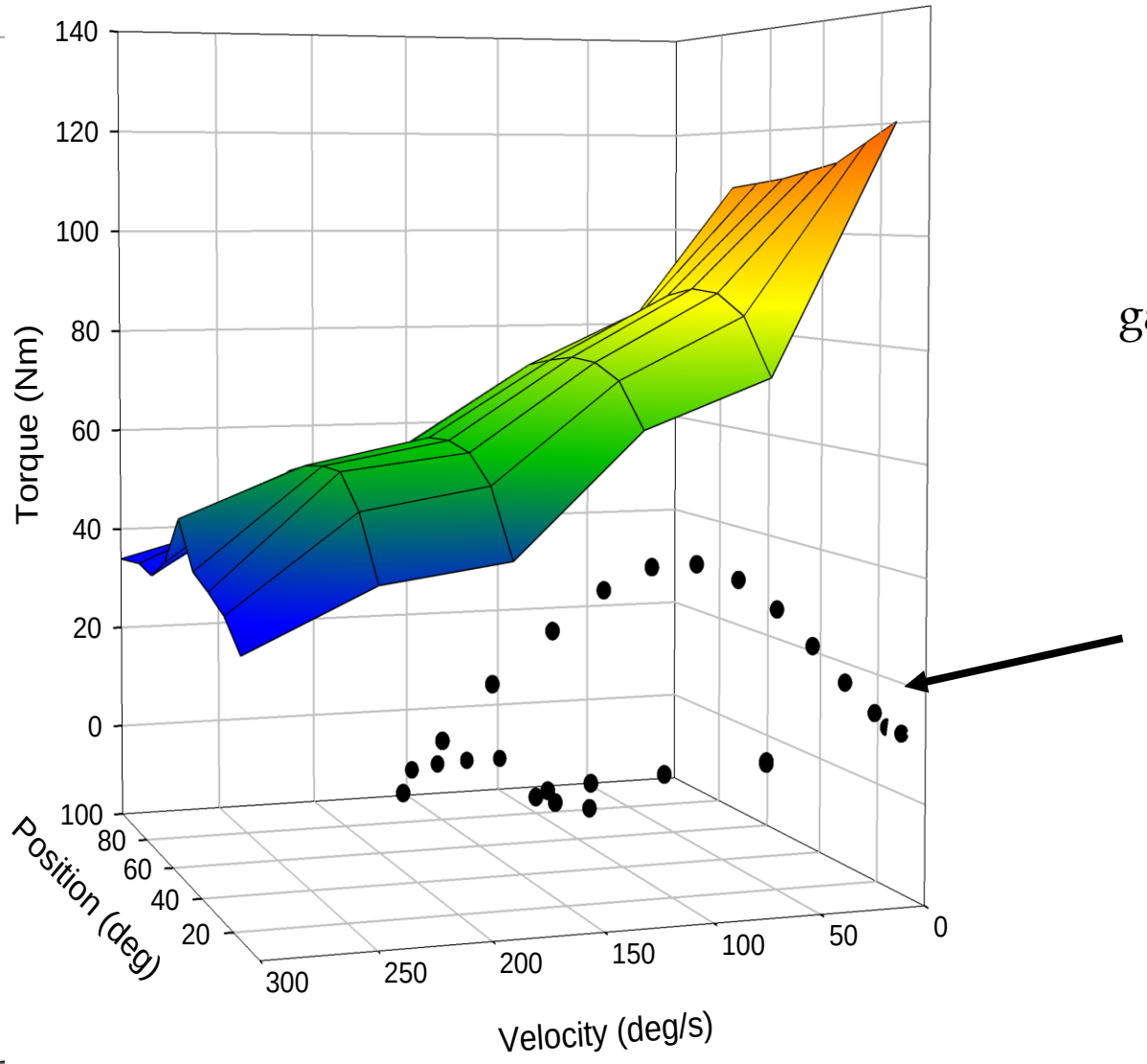
Add dynamic constraints
Add cognition/learning
Refine and check robustness

- Draft experimental protocol
- Get **IRB** approval
- Recruit subjects
- Perform experiments

Experimental Studies Conducted under ETOWL

Dynamic Strength Experiments



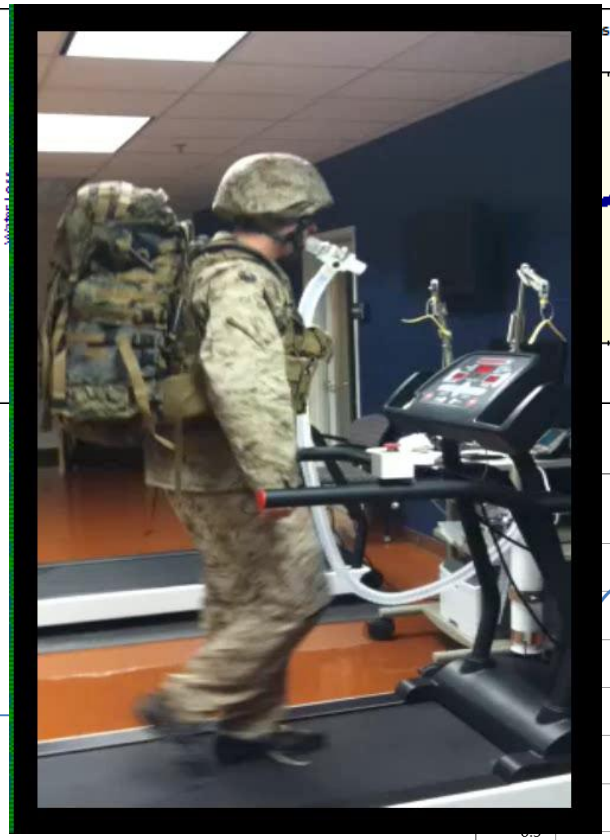


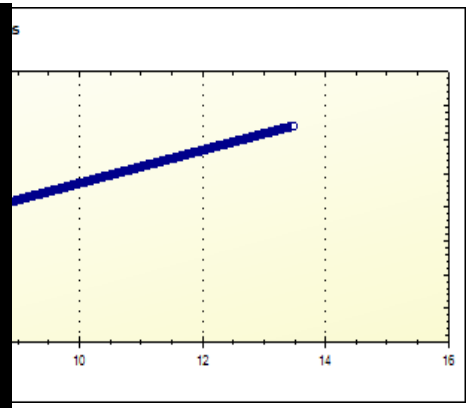
gait with 40 lb backpack
knee joint
50% strength

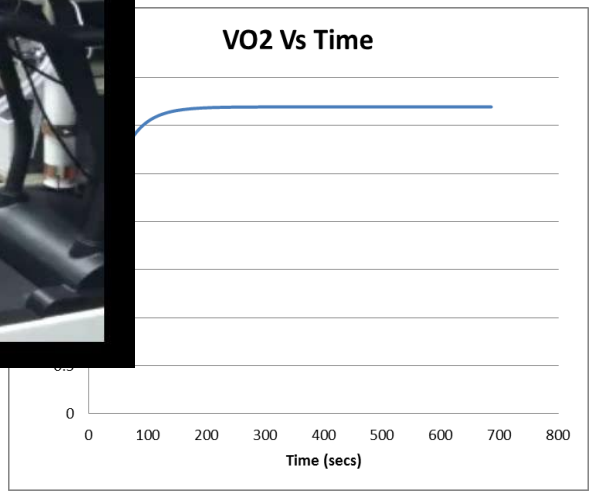
Extended Load Carriage

Case 2: 15km in 3 hours 45 mins

Input	
Male	• Average Marine
Weight	• 75Kg
Distance	• 15km
Time	• 3 hours 45 mins
Speed	• 1.11 m/sec
External Load	• 50-60 lbs (22.62- 27.14 Kg)
Terrain factor	• Paved road
Slope	• flat



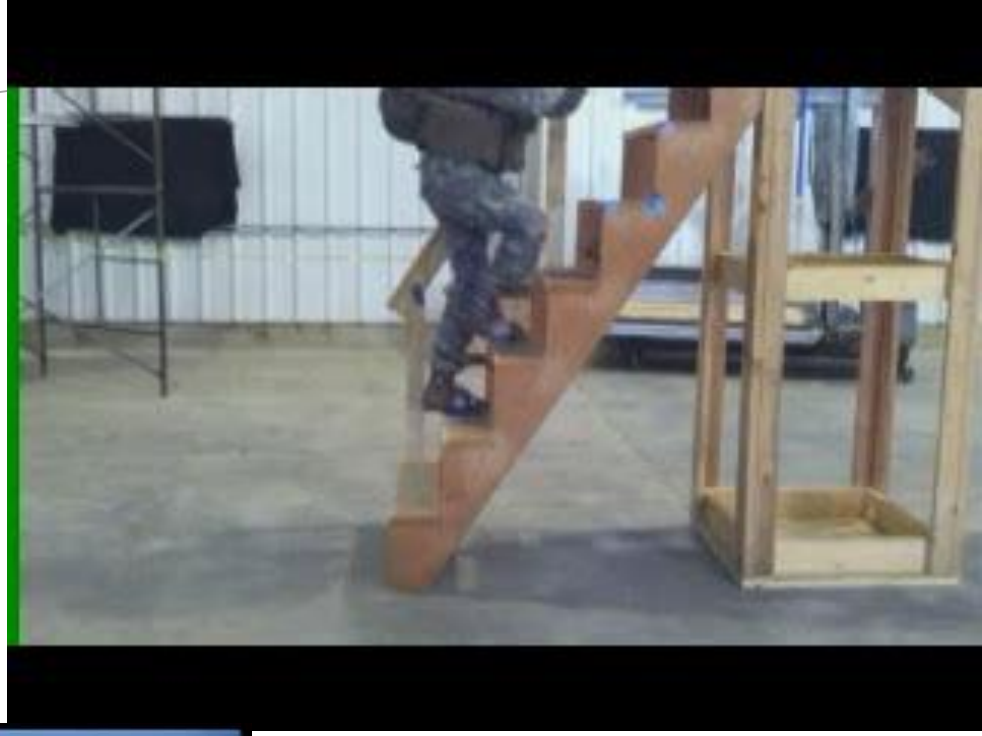


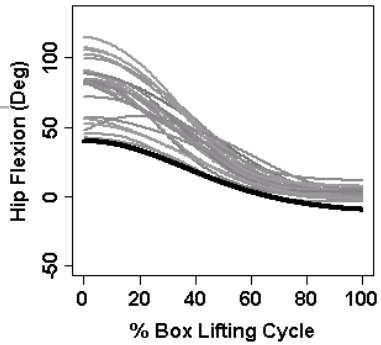


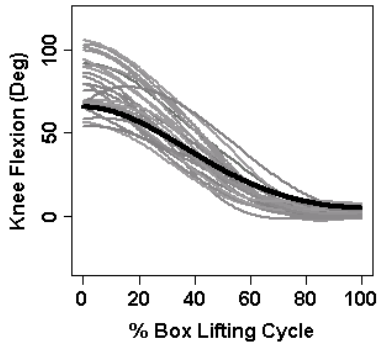
Output	
Fatigue levels	• 3.11 L/min or 78% of max
Energy expenditure	• 319.58 Watts or 274 kcal/hour

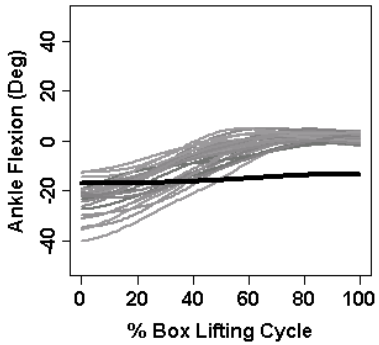
Assumptions	
Weather	• Iowa City conditions 31C (87F),79% humidity,
Marine weight	•75 Kg
Strength and fitness	•Average, fatigue effects ignored

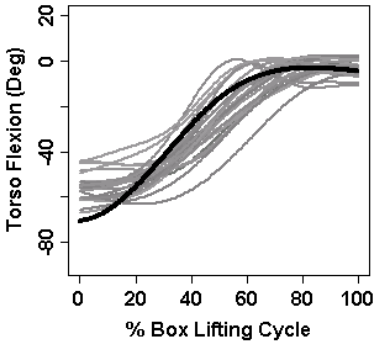
Task Validation

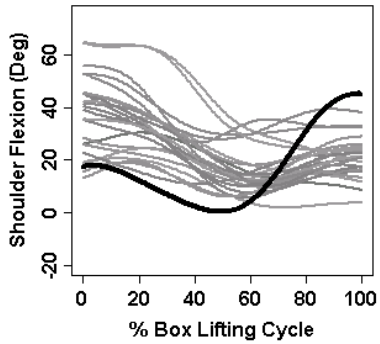


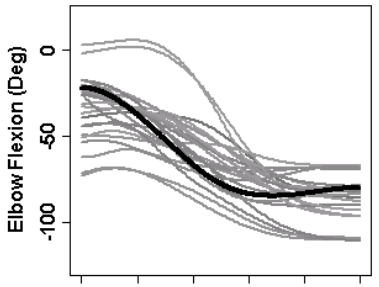

Hip Flexion (Deg)
% Box Lifting Cycle

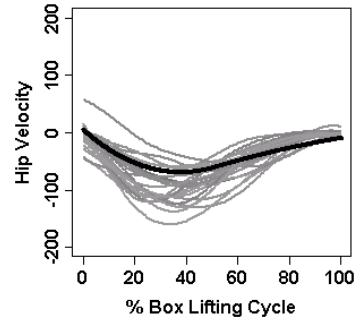

Knee Flexion (Deg)
% Box Lifting Cycle

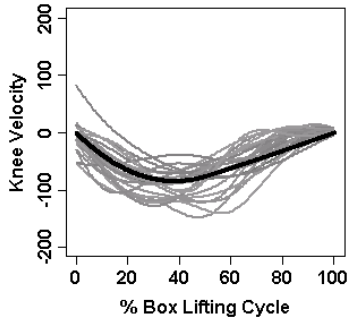

Ankle Flexion (Deg)
% Box Lifting Cycle

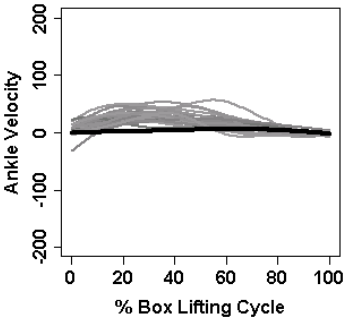

Torso Flexion (Deg)
% Box Lifting Cycle

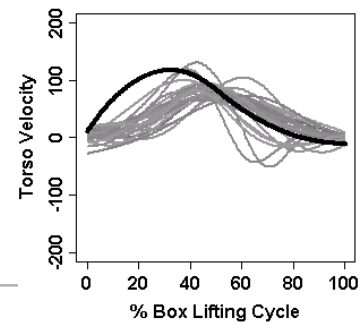

Shoulder Flexion (Deg)
% Box Lifting Cycle

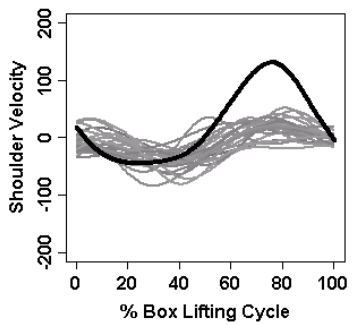

Elbow Flexion (Deg)

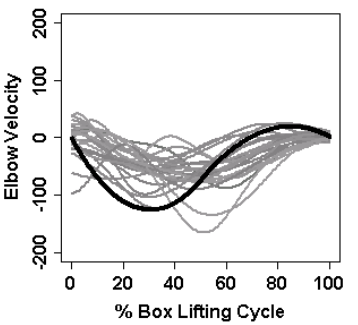

Hip Velocity
% Box Lifting Cycle


Knee Velocity
% Box Lifting Cycle


Ankle Velocity
% Box Lifting Cycle


Torso Velocity
% Box Lifting Cycle


Shoulder Velocity
% Box Lifting Cycle

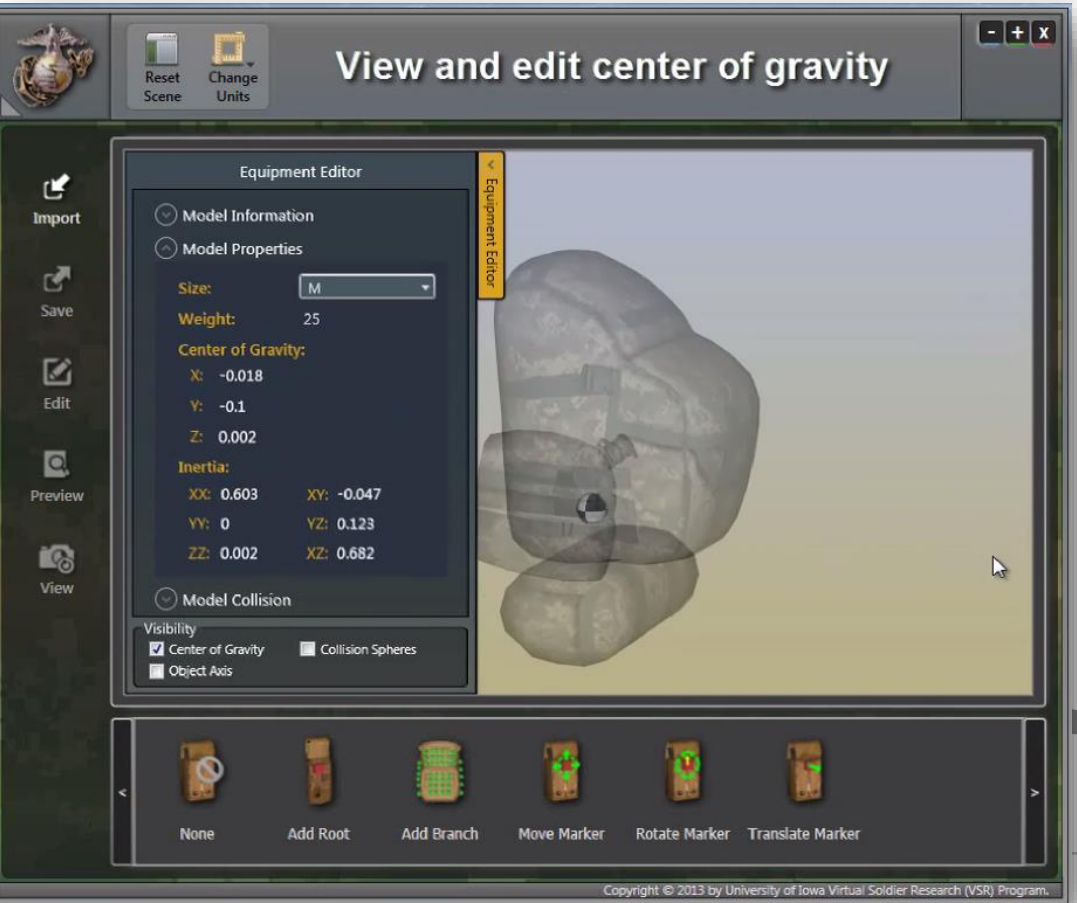

Elbow Velocity
% Box Lifting Cycle

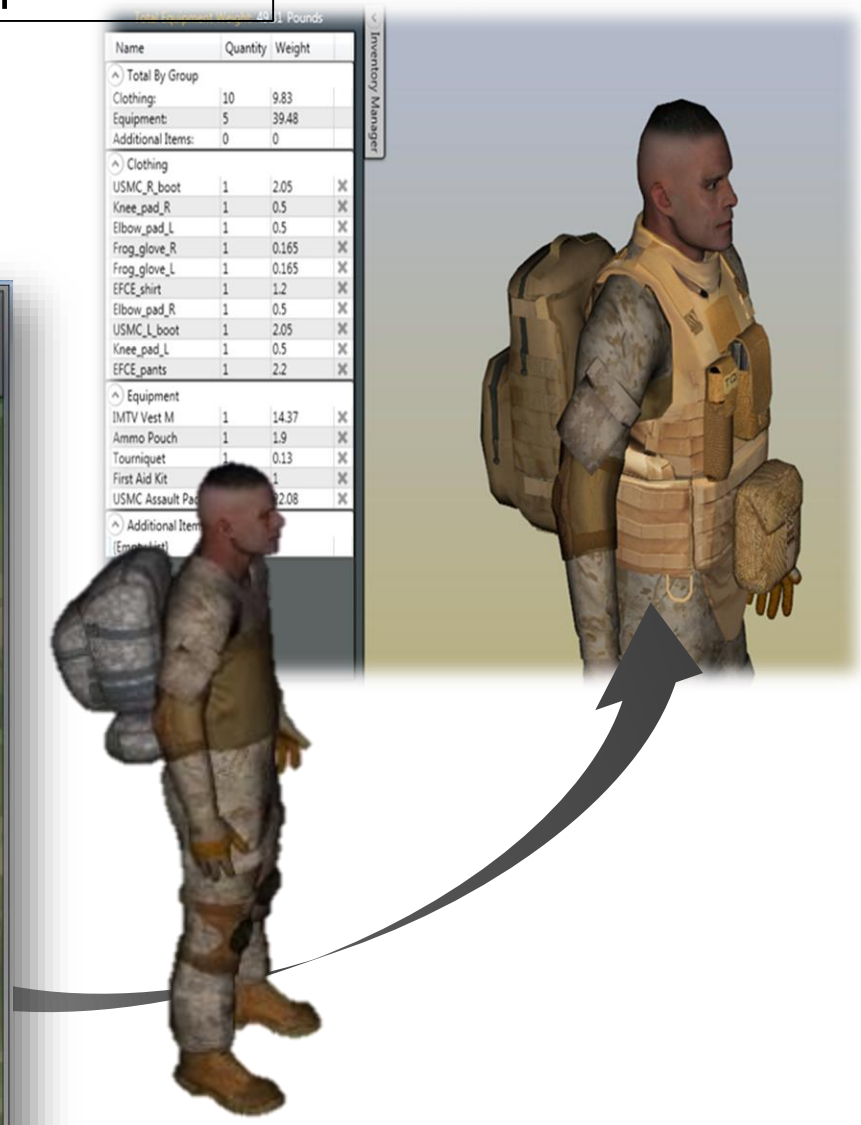
ETOWL Software demonstration

GruntSim – Equipment and Models

- Import equipment
- Large selection of gear
- Accurate models
- Attachment to body

- Configure the load
- Pick and place





GruntSim – Warrior Configuration

https://youtu.be/iHJipX83GmI

- ✓ Intuitive
- ✓ Drag-and-drop
- ✓ Weight and Volume Analysis
- ✓ Range-of-motion Analysis
- ✓ Stability Analysis
- ✓ Cocoon Analysis

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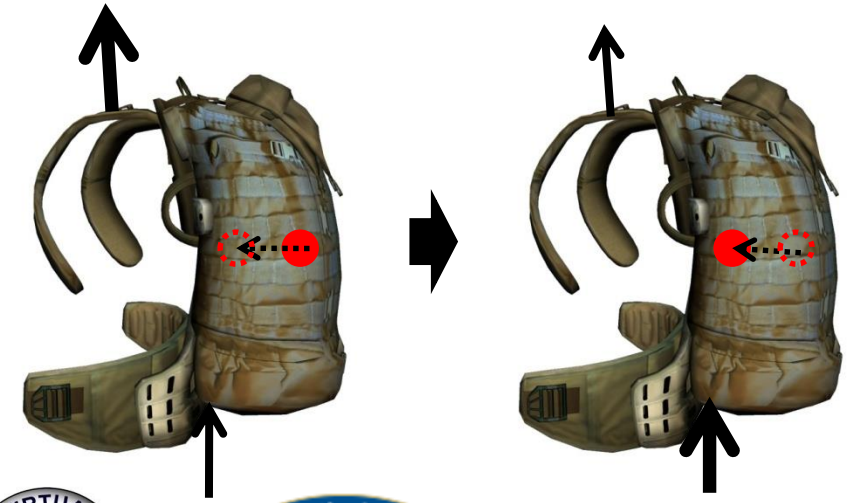
Science & Technology

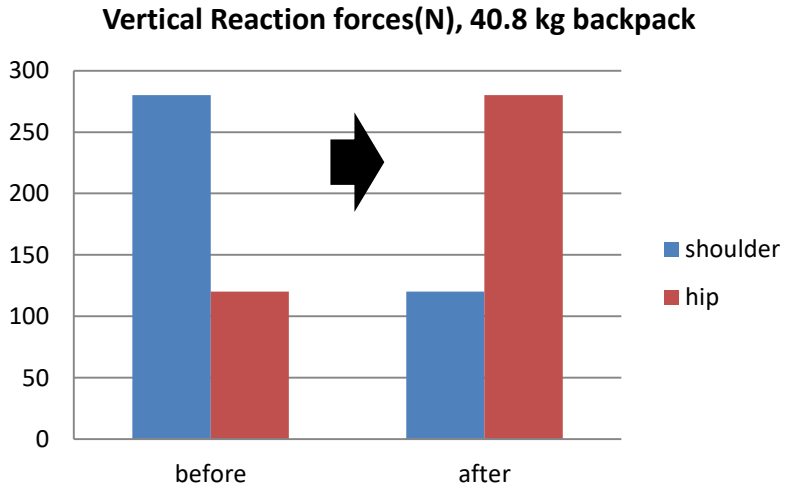
Equipment Simulation – Static Load Analysis

Example: Jammer Pack 3D Model

- Posture analysis
- Soldier's load and combat readiness

Example: Changing CG





GruntSim – Warrior Configuration

Configure the Warfighter and perform weight, volume, and "cocoon" analysis

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Warrior Performance – Dynamic Task Analysis

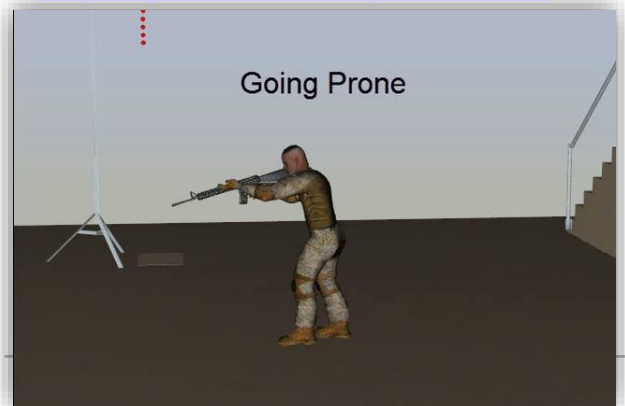
https://youtu.be/DIccUCOkKek

Training and analysis

- Asymmetric loading
- How to carry loads
- How to perform a task
- Effects of Biomechanics
- Cause & Effect
- Effect of C.G.
- Learn to avoid possible errors

https://youtu.be/qpl7uhxMz7I

https://youtu.be/EAqoJNwbAUI



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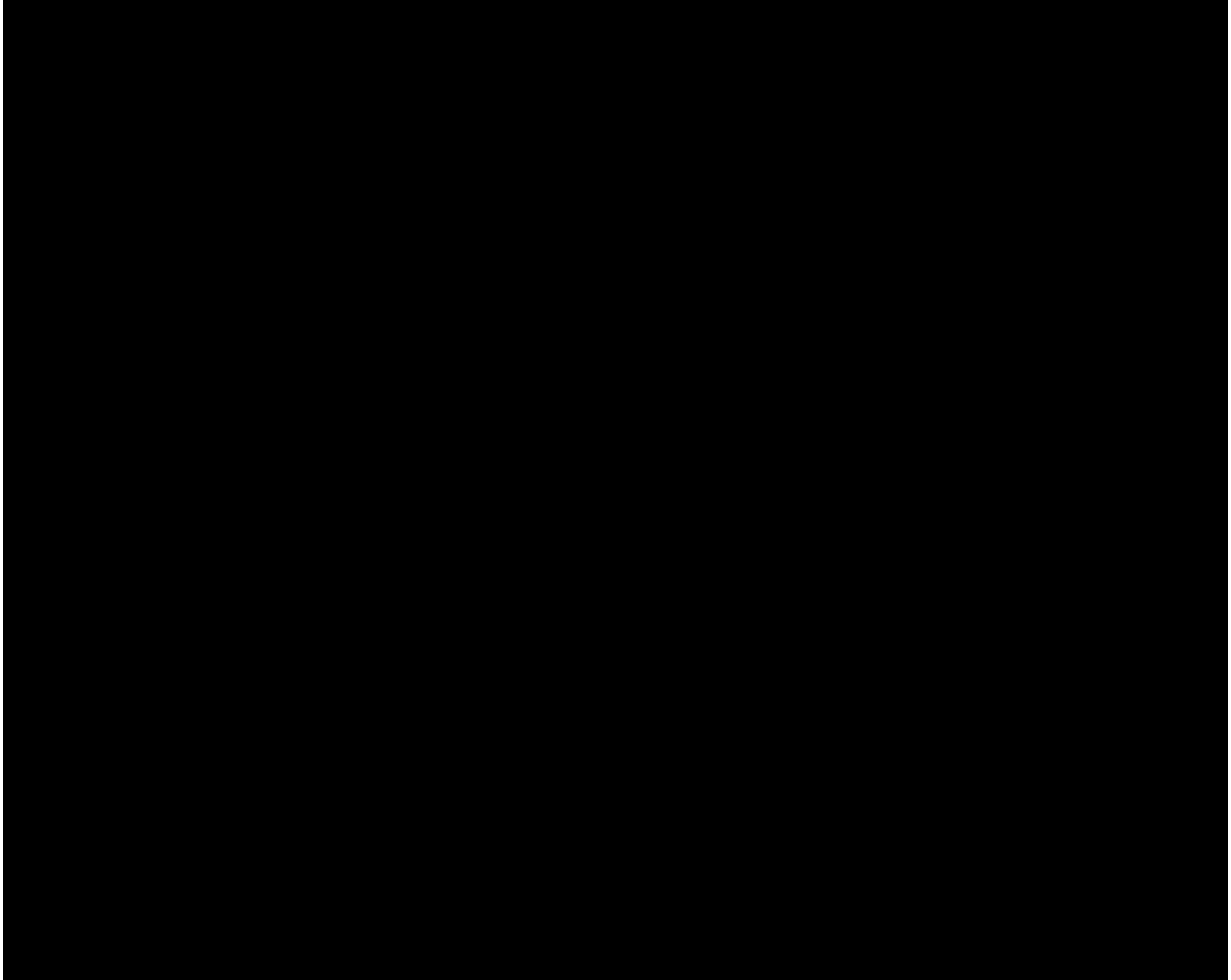
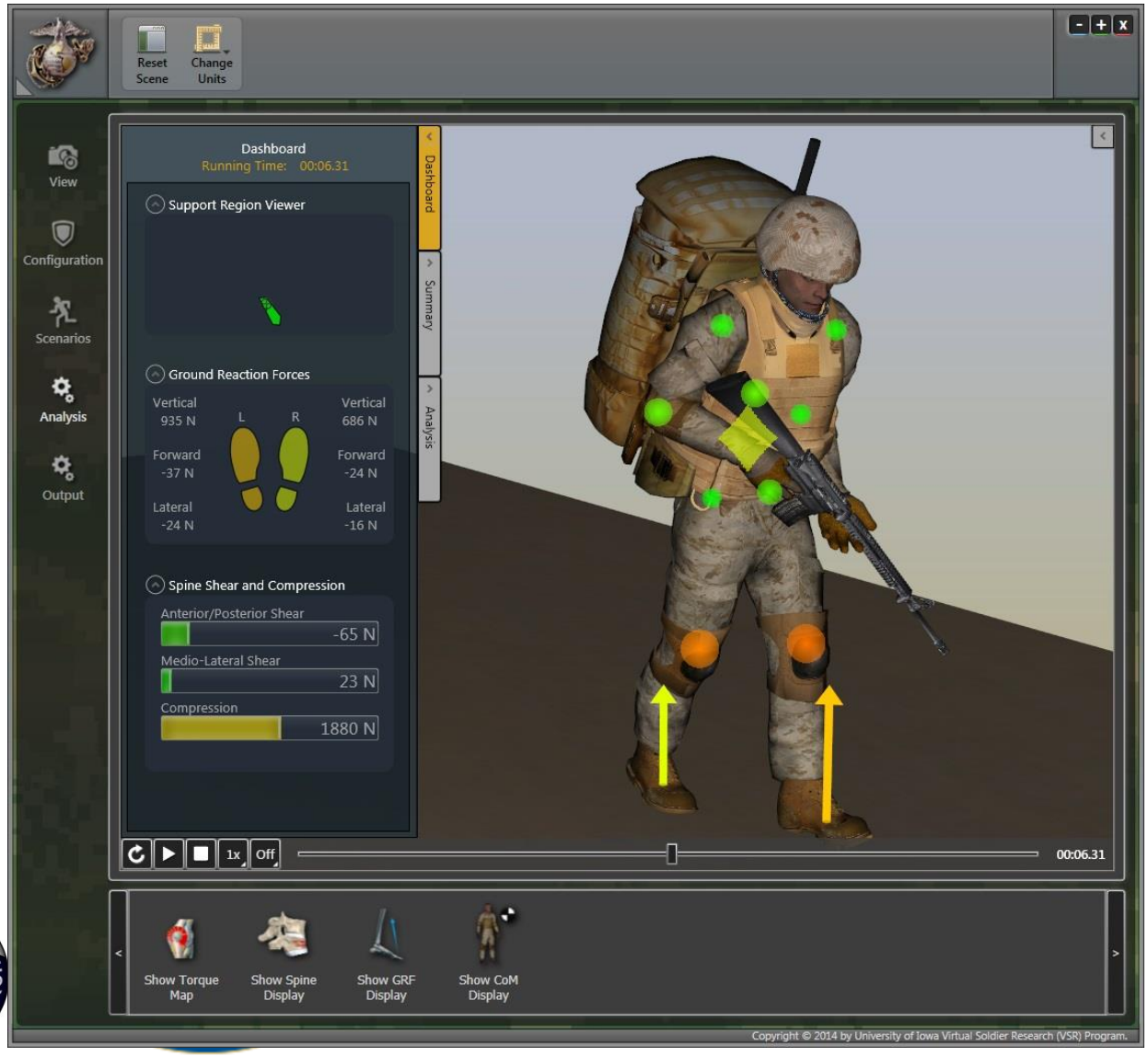


GruntSim™

https://www.youtube.com/watch?v=XTJFhR-D418



Transitioned to the Marine Expeditionary Rifle Squad (MERS)

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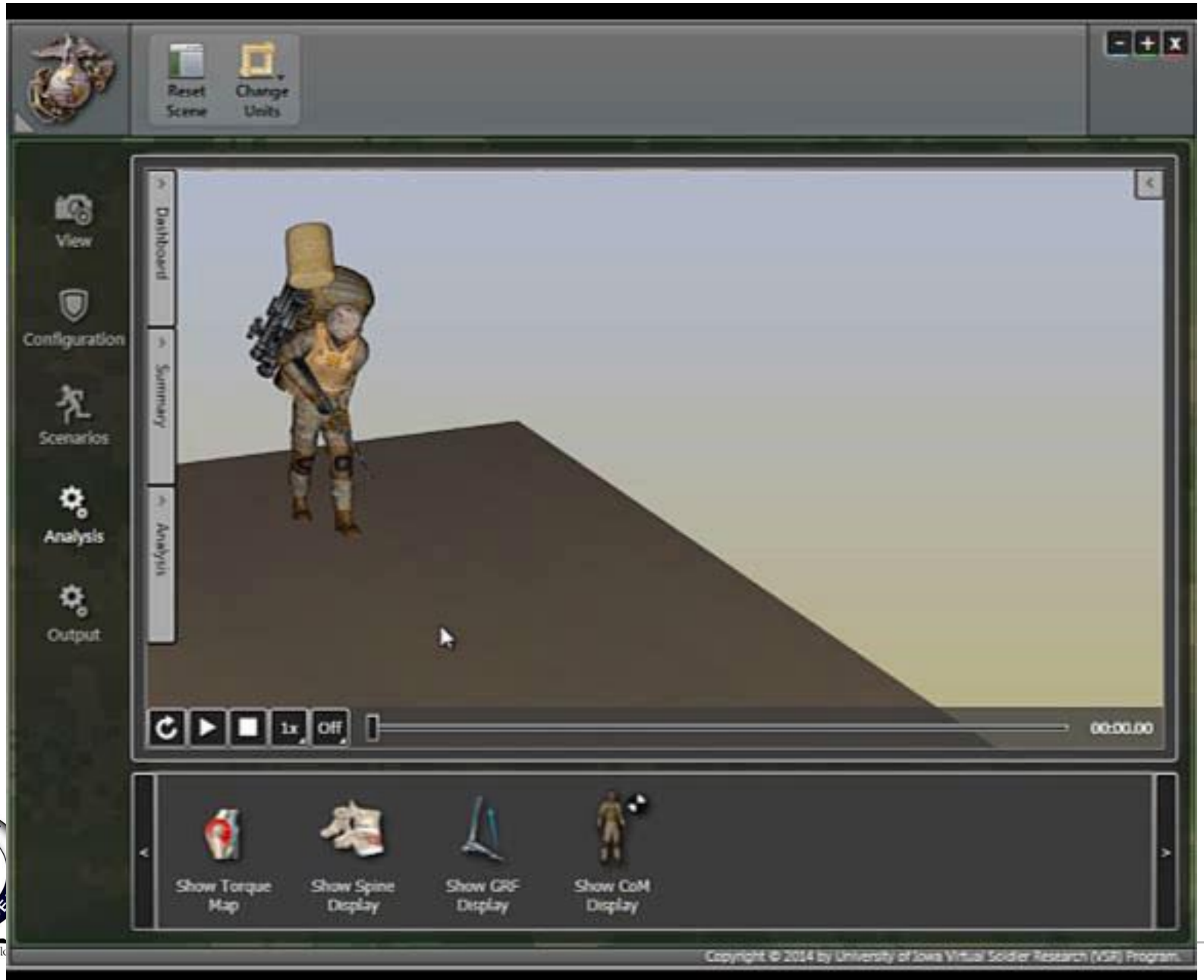
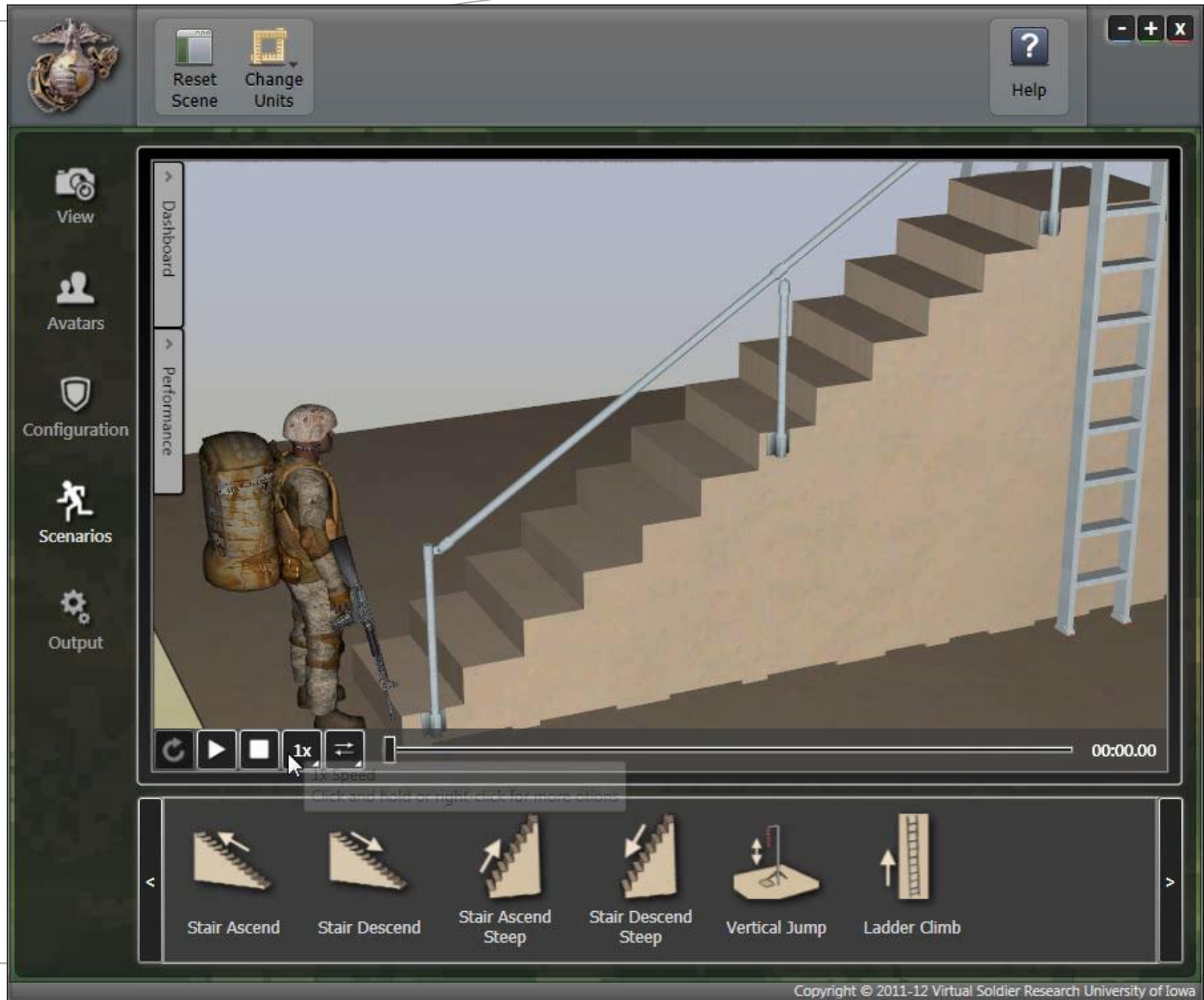
Warrior Configuration

Asymmetric Heavy Load



Simulation Builder



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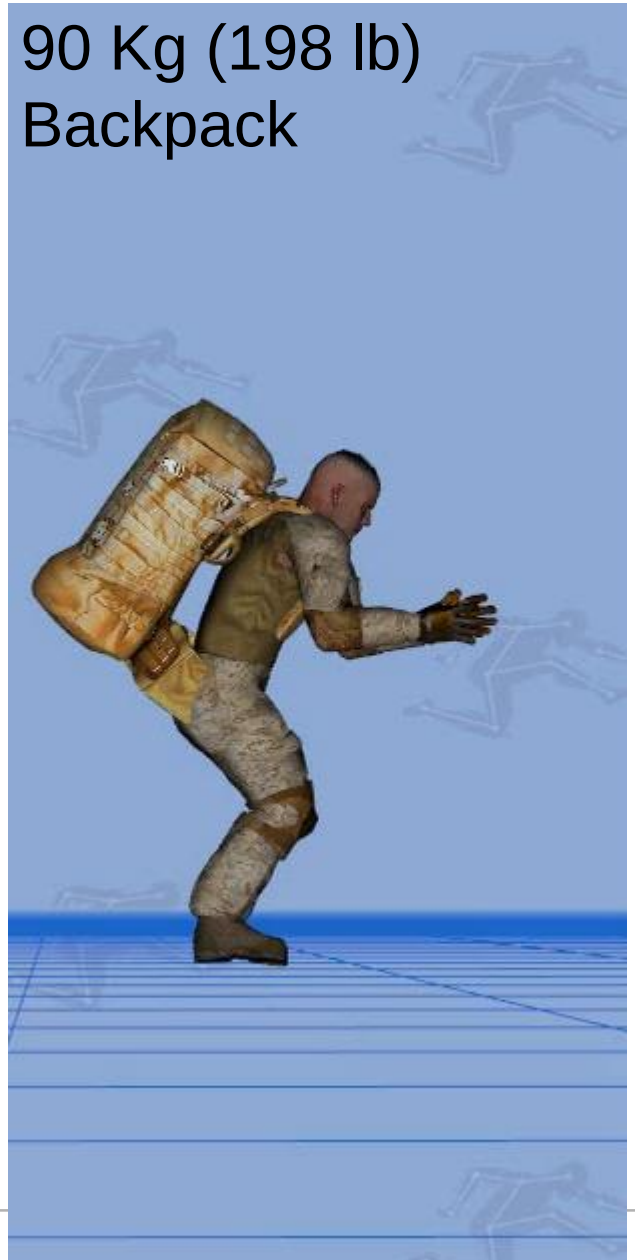
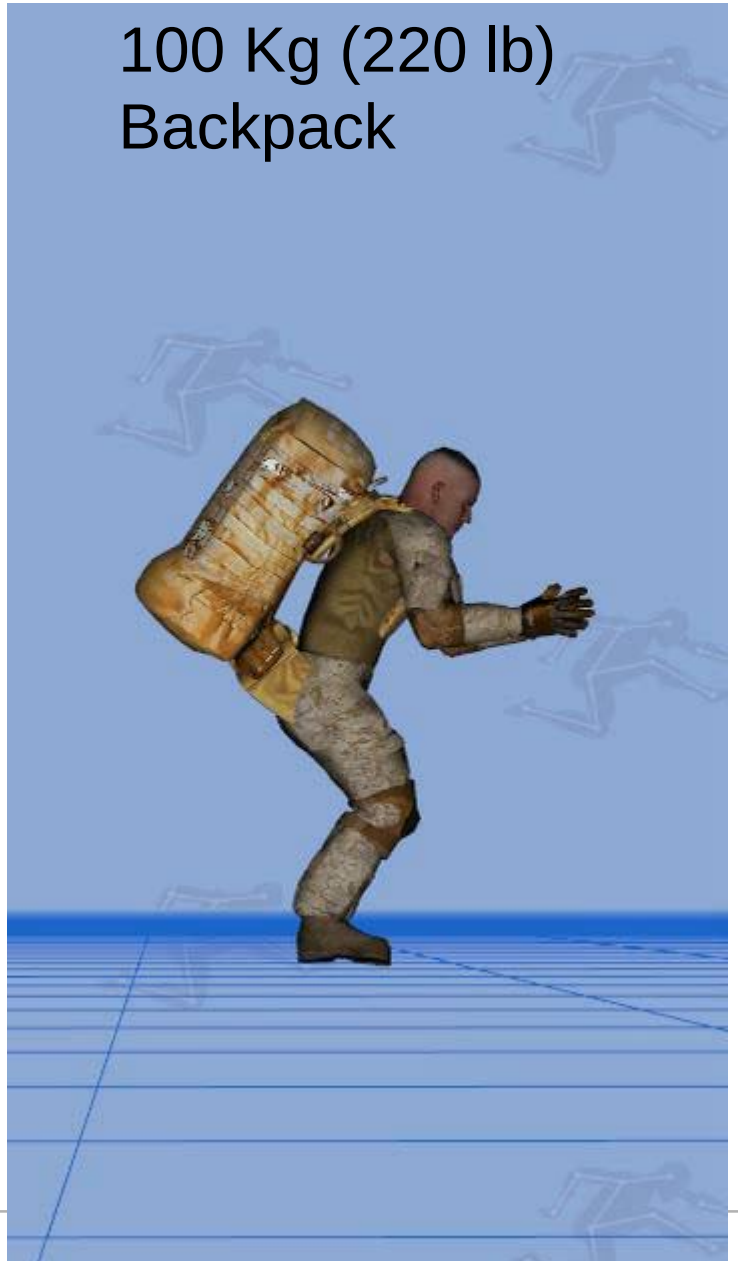
Cause and effect

No Backpack

90 Kg (198 lb) Backpack



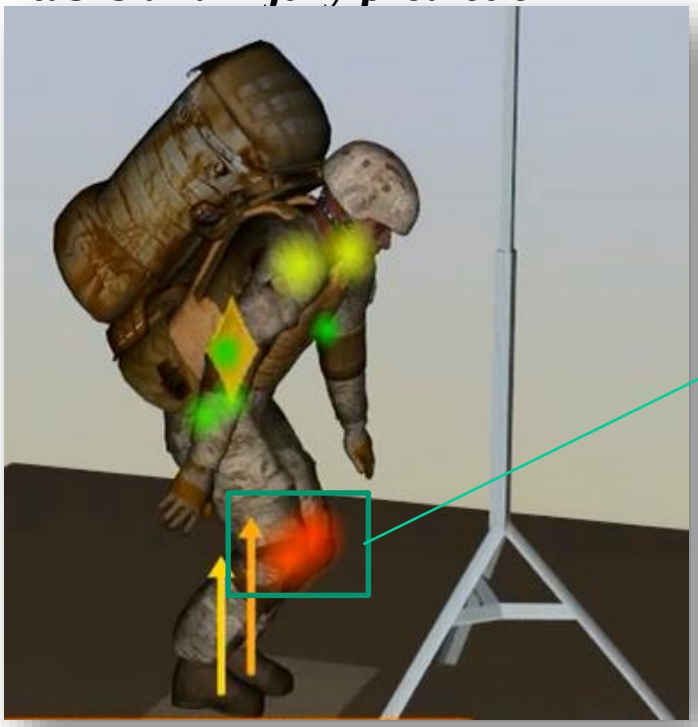
100 Kg (220 lb) Backpack

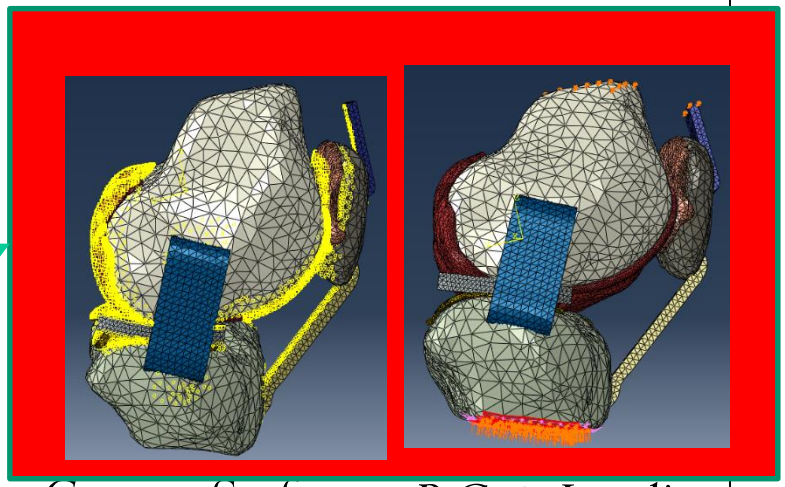


Injury Prediction

Injury Prediction:

- ***Physics-based human motion prediction (predictive dynamics) for simulating tasks and injury prediction***



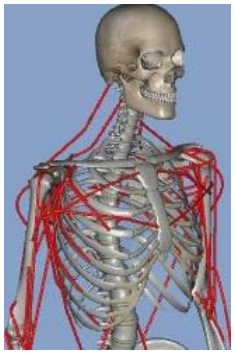


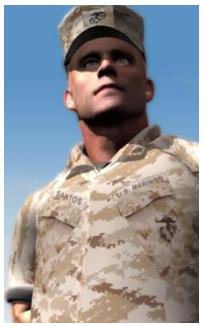
Contact Surfaces B.C. & Loading

Joint limits
Ground penetration
Foot strike position
Dynamic stability (ZMP)
No slip
Symmetry condition
Equations of motion
Etc.

99128 Elements,
C3D4 Tetrahedral

History of Santos




2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015

Robotics
Optimization
Biomechanics
Interactive
Real time
High fidelity
CAD import

Posture prediction
Ergonomics

Strength & fatigue

Real-time

Task simulation

Musculoskeletal Inju

Vision

Physiology

Armor

Realism
Anthropometry
Physics based

Thermal, hydration, energy

PPE-Blast

Human Predictive dynamics

Psychological

Hand & grasping

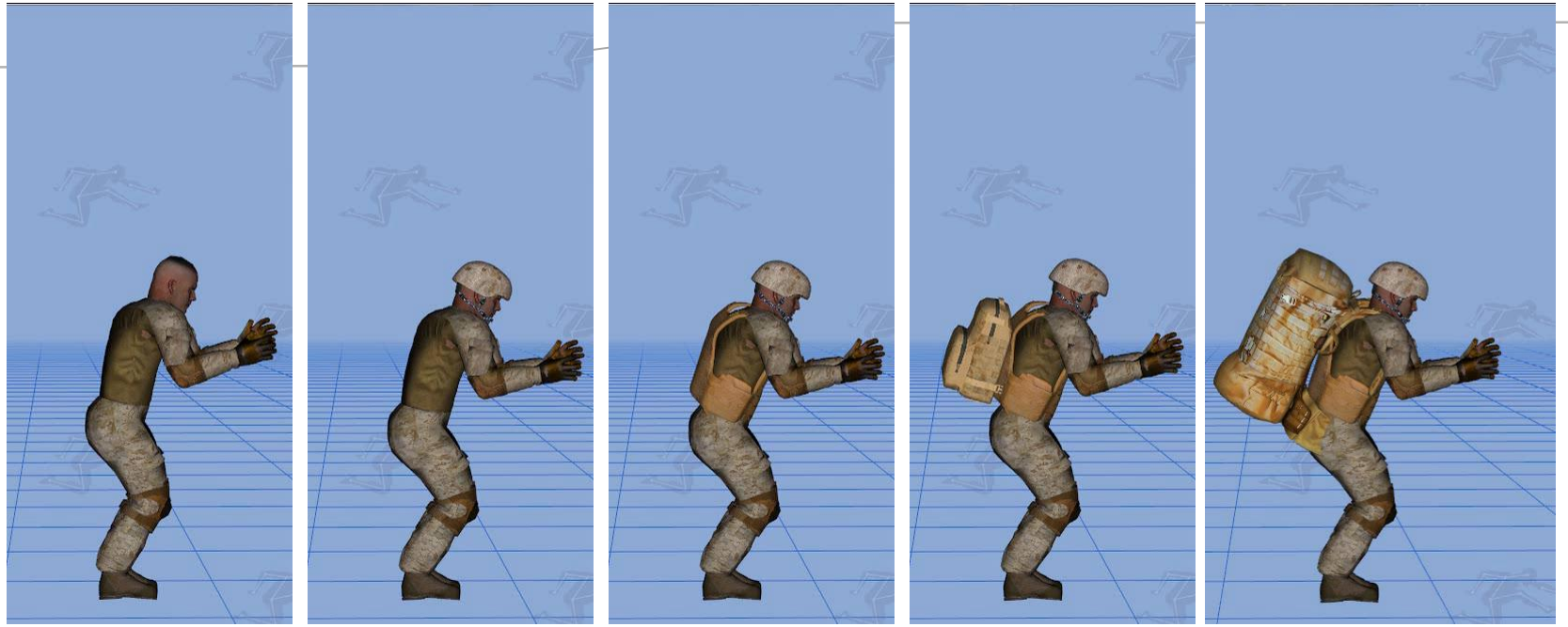
Human performance

Clothing/armor

Validation Validation Validation Validation Validation

Height (m)

2.498672	2.401209	2.310071	2.131725	1.990143
Santos 79 kg				
2.180130	2.174497	2.119108	2.015748	1.946092
Man3 111 kg				



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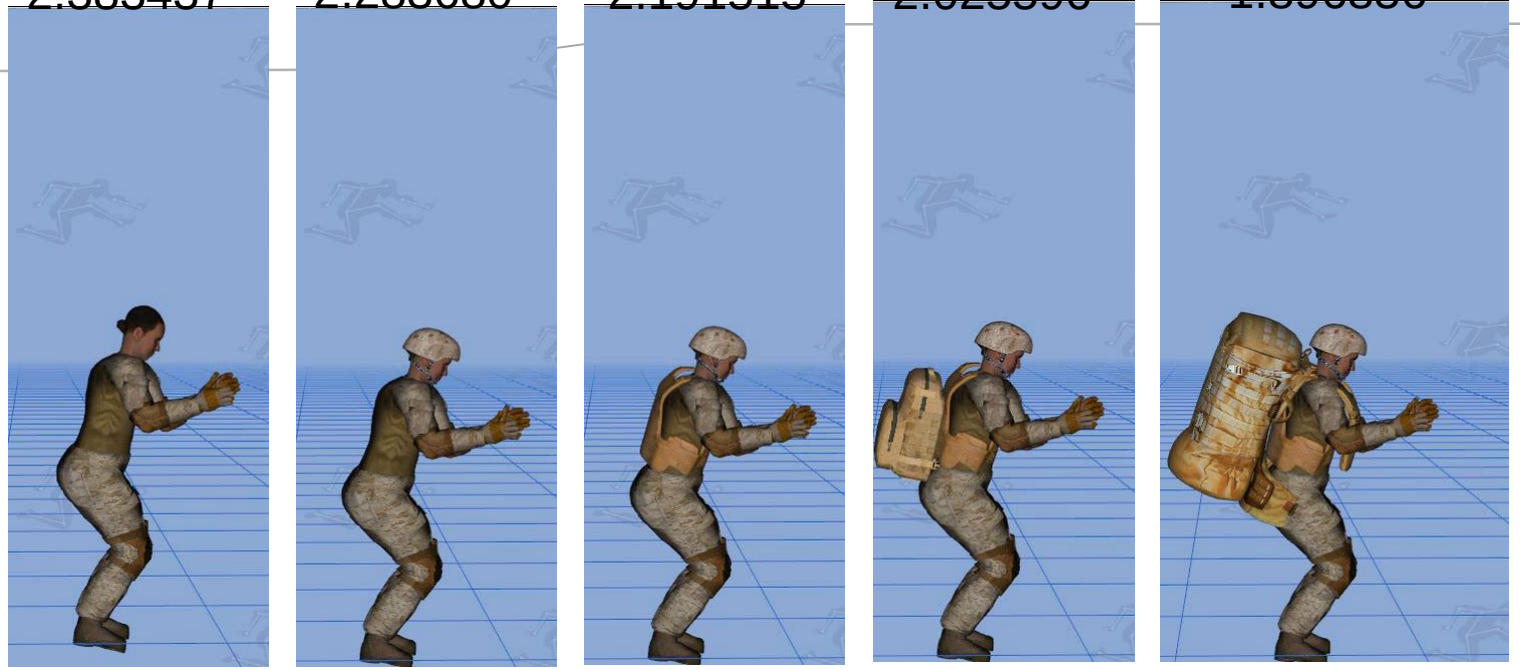
Height (m)

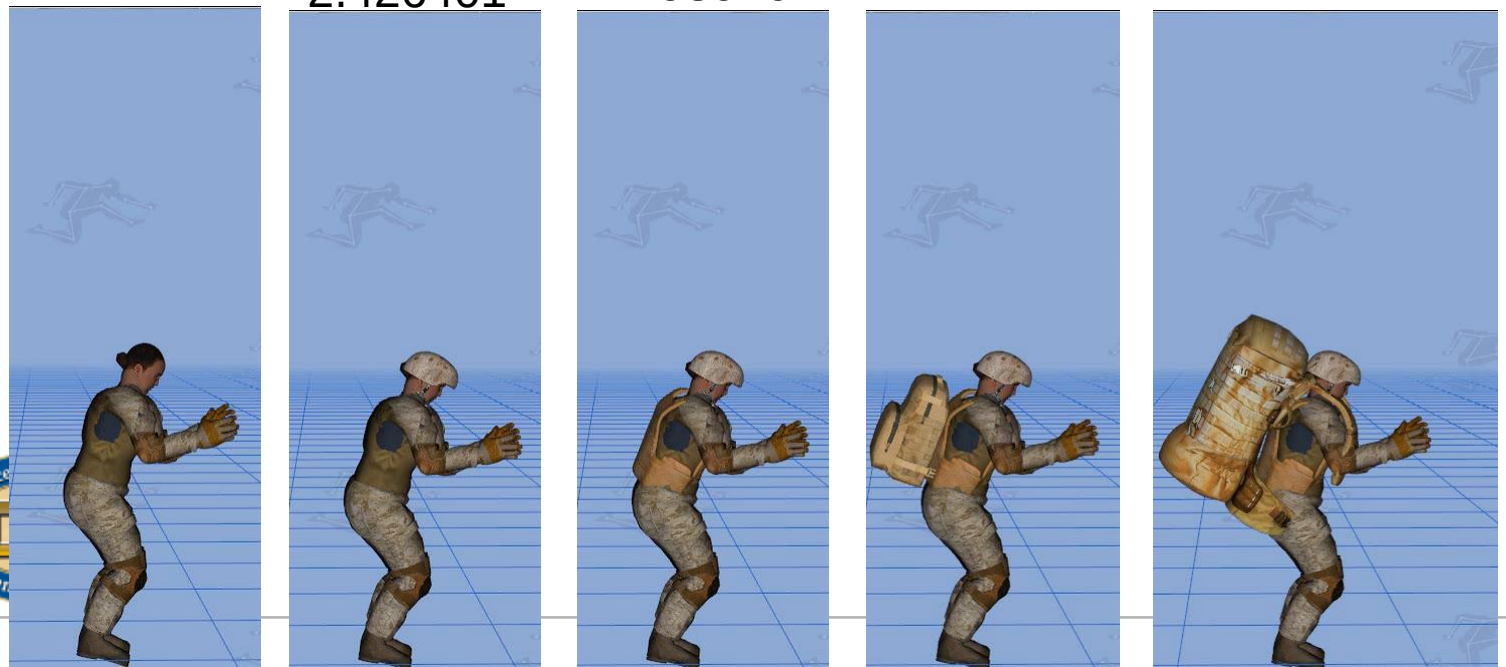
2.383437 | 2.283680 | 2.191515 | 2.025596 | 1.896856

Sophia
60 kg



2.511551 | 2.426401 | 2.298920 | 2.089685 | 1.932893

Woman1
51 kg



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“ETOWL (GruntSim) fits perfectly within ONR’s mission to develop groundbreaking technologies that enhance the resilience, physical superiority and overall warfighting performance of U.S. Marines,”

Brig. Gen. Kevin Killea
Vice Chief of Naval Research

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Office of Naval Research
ONR
Science & Technology

“The benefits of ETOWL are numerous, said. For example, the Marine Corps can use data from the virtual tests to quickly design real-world prototypes for testing by live Marines.”

“It’s very exciting to see ETOWL transition from ONR prototype to a technology that will enhance human load and performance for the Marine Corps, this is the kind of research that’s very rewarding because it provides a direct benefit to our nation’s warfighters.”

Dr. Peter Squire
ONR Program Manager
Expeditionary Maneuver Warfare and Combating Terrorism department

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MARINES
THE FEW. THE PROUD.®

Women in Combat

The Future

- ✓ Automated task development
- ✓ Expanded libraries of models and tasks
- ✓ Increased intelligence and learning
- ✓ Training aid
- ✓ Injury prediction and avoidance

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Thank you!

Contact:
Karim Abdel-Malek, PhD
Professor and Director
Virtual Soldier research
University of Iowa
amalek@engineering.uiowa.edu

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