INTRODUCTION

Warfighter performance is inherently challenging to monitor, quantify and ultimately interpret. These challenges originate from the varied and complex tasks that warfighters perform, the underlying variability in human task performance, the environments in which they operate, and a limited knowledge of the measures that truly characterize task performance success/failure. Adding to these challenges are the confounding effects on physical performance due to equipment (e.g., load, bulk and stiffness), task training, and explicit performance degradation. Our ongoing research in this rapidly growing area aims to address these challenges by engineering and evaluating a complete performance approach to quantify and report warfighter performance in naturalistic outdoor environments.

Continued efforts rest on advancing our ongoing research utilizing body-worn arrays of miniature inertial measurement units (IMUs) that synchronously measure and transmit data defining the spatial mechanics of major body segments and their interactions with external equipment. Our current array utilizes up to ten IMU nodes attached to the task-relevant segments/equipment of interest. The IMU data encode the thumbprint of task performance. For example, during walking or running gait, performance metrics include timing events (e.g., ground contact), gait speed, and explicit segmental dynamics. To date, we have developed an integrated functional IMU array and companion (Matlab™ based) computational algorithms for analysis of select warfighter tasks. Currently the end user is required to have significant expertise in human biomechanics, experimental methods, and software development/manipulation to implement the integrated system in a functional setting. Current efforts aim to mitigate these limitations and extend system capabilities by engineering and evaluating a fully automated measurement system. Our ultimate goal is to deliver an integrated hardware/software system that enables easy and reliable assessment and comparison of warfighter performance. Specifically, we will generate a complete measurement system that discriminates warfighter performance using IMU data within naturalistic (and often random) movement environments encountered by the warfighter.

METHODS

We have collected data on a large number of young healthy subjects, both for the purposes of the IMU-based system validation and to subsequently assess the effects of load-carriage within a simulated warfighter environment [1, 2]. For the purposes of validation, we compared a number of IMU-derived body and segmental kinematical measures during a variety of (e.g., walking, running, jumping, rifle aiming) movement tasks to those obtained via “gold-standard” motion capture techniques. Mocap derived data were generated using or well established methods [3]. Load-carriage effects were evaluated with the validated IMU-system for subjects moving within an outdoor obstacle course. The course was consistent with those adopted.
within the military, containing a series of running, jumping, crawling, climbing and rifle aiming tasks. Specifically, subjects completed the course with and without additional (20.5kg) load.

Throughout the testing protocol, subjects had eight wireless IMUs (Opal, APDM, Inc.) secured to specific body segments (feet, shanks, thighs, sacrum, and torso). Each IMU contains a 3-axis accelerometer, angular rate gyro, and magnetometer; a proprietary Kalman filter estimates the directions of gravity and magnetic north relative to sensor-fixed axes. Subjects initially perform calibration movements to determine segment-to-sensor alignments for post-processing purposes.

**RESULTS AND DISCUSSION**

Results from our extensive efforts to date have yielded four major findings; namely: 1) IMU-derived kinematical measures of human movement accurately replicate those determined from standard motion capture; 2) these kinematical measures distinguish performance in a spectrum of highly relevant warfighter tasks; 3) our chosen performance measures are sensitive to extreme load carriage (e.g., loaded versus unloaded), warfighter fitness and/or task induced performance degradation (e.g., fatigued versus non-fatigued); and 4) IMU technology and the embedded algorithms readily translate to and be largely immune to the inherently random nature of outdoor environments. More specifically, our validation experiments have revealed excellent agreement between IMU and mocap measurements of linear acceleration and angular velocity as well as quantities derived therefrom, including linear velocity and angular orientation. Less accurate, in general, are position estimates, particularly for unconstrained tasks, which is consistent with the raw data being measured by a sensor, as position would be an integrated parameter from the raw velocity and acceleration signals. A key outcome of our obstacle course work, which is particularly relevant to the already encumbered warfighter, is that a rich and highly applicable dataset can be generated with a minimum number of sensors. For example, walking and running performance can be successfully quantified and compared across (e.g., load and or performance degradation) conditions using relatively straightforward IMU-derived gait parameters (e.g., stride period, length, and speed; duration of single/double support phases and swing phases). Similarly, jumping, climbing and landing performance can be successfully quantified and compared using sacral IMU-derived measures of vertical acceleration and velocity as well as jump height.

**CONCLUSIONS**

Our research provides an innovative and critical vertical step in field-based warfighter performance assessment techniques. Specifically, we have shown that meaningful and readily comparable and translatable performance outcomes can be obtained from a small number of body-worn miniature IMU sensors. By extending beyond the confines of the traditional laboratory setting, this approach will ultimately enable warfighter performance to be successfully monitored and optimized within a variety of complex and often random environments. Moving forward, we will extend our approach to more effectively characterize critical movement metrics that can consistently distinguish levels of performance success. Additionally, we will automate the assessment approach so that it can be used by the non-expert evaluator. Through these steps, we expect this integrated technology will readily translate to a variety of clinical settings.

**REFERENCES**


**ACKNOWLEDGEMENTS**

Supported by NSRDEC W911QY-13-C-0011.