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PRINCIPAL INVESTIGATOR: Peter Weyand

CONTRACTING ORGANIZATION: Southern Methodist University, Inc.
Dallas, TX 75275

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Peter Weyand

E-Mail: pweyand@smu.edu

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14. ABSTRACT
Walking is a primary form of physical activity that has fundamental effects on the physiological status of the soldier: caloric requirements, heat and hydration status and mission readiness of soldiers can all be directly impacted by the locomotor metabolic rates that they incur in the field. The objective of the current work isto use our energetics-mechanics model to develop basic relationships between height, weight (body, or body + load), walking speed and the metabolic cost of walking in the laboratory and to apply these quantitative relationships to improve estimates of the metabolic cost of walking in the field. Our first hypothesis is that the generalized equation provided by our new gait mechanics model predicts the metabolic cost of weighted and unweighted walking more accurately than existing generalized equations. Our second hypothesis is that weighted and unweighted walking metabolic rates can be estimated in field settings from simple technologies such as gps monitors and pedometers.

15. SUBJECT TERMS
Locomotion, gait, metabolism, body size, load carriage

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INTRODUCTION

Walking is a primary form of physical activity that has fundamental effects on the physiological status of the soldier. The speeds at which soldiers walk and loads they support while doing so determine the rates at they expend metabolic energy and produce heat. Accordingly, their caloric requirements, heat and hydration status and mission readiness can all be directly impacted by the locomotor metabolic rates that they incur in the field.

The proposed work has two objectives to improve prediction and assessment capabilities. The first objective is to determine if the generalized equation provided by our new gait mechanics model predicts the metabolic cost of weighted and unweighted walking more accurately than existing generalized equations. Our second objective is to determine how accurately weighted and unweighted walking metabolic rates can be estimated in field settings from simple technologies.

Metabolic rates will be measured from expired gases. The timing of each walking stride, as well as its subcomponents (i.e. the contact and leg swing portions) will be determined from video. In addition, the periods of muscular activity responsible for executing the movements of the walking stride will be also assessed from electrical activity using surface electrodes attached to the skin above target muscles. The forces that subjects apply to the ground during locomotion may be measured from either a force plate or force sensors built into a treadmill. Finally, heart rate monitors to measure heart beat frequency, miniature motion sensors mounted to the shoe or other parts of the body to measure movement speeds and rates may also be utilized.

The specific tasks identified in the statement of work for the second and upcoming award period are:

1) Quantitative relationships that predict walking metabolic rates from height, weight (body weight + load) and walking speed and based on the our mechanics-energetics model.

2) Laboratory validation of the algorithms provided by the model on an independent sample of subjects,

3) Assessment and validation for use of the model’s algorithms in the field with both inexpensive technologies and timing devices.

The specific tasks identified in the approved statement of work for the first award period were:

1. To determine the relationship between all-out exercise performance and anaerobic and aerobic sources of metabolic power during modes of exercise involving a significant fraction of the body's muscle mass

2. To determine the briefest testing protocol that will accurately quantify the anaerobic and aerobic fitness of soldiers or an equivalent population.

3. To determine whether the progressive recruitment of additional muscle motor units during fatiguing exercise is a factor that forces the cessation of the exercise or a decrement in performance.

BODY:

Official approval for testing of human subjects for the second round of proposed work is currently pending

KEY RESEARCH ACCOMPLISHMENTS:

The key research accomplishments from the first award period, as provided in the final report for that period were:

- Validation and extension of the anaerobic reserve model to two modes of whole-body exercise: cycling and locomotion.
- Development of two new techniques for quantifying anaerobic and aerobic fitness
  - Two-trial procedure
  - Modified Wingate (single trial)
- Establishing a mechanistic link between muscle fatigue and the exercise performance-duration relationship.
- Identification of muscle force decrements (i.e. fatigue) rather than metabolic power, as the factor limiting brief all-out exercise performance.
- Finding that rates of muscular fatigue during intense whole-body exercise: 1) vary directly with intensity, but 2) do

not seem to vary between different muscles (i.e. no bottlenecks, all contributing muscles fatigue equally).

Experimental work on the newly proposed experiments for the second award period has not yet commenced as human subjects approval is pending.

REPORTABLE OUTCOMES:

Reportable outcomes from the first grant award period, as reported and updated since the final report on the first award period were:

Manuscripts

Weyand, P, Bundle, MW, McGowan, C, Grabowski A, Brown, MB, Kram, R and Herr H. The fastest runner on artificial limbs: different limbs, similar function? *Journal of Applied Physiology*.

Bundle, MW, Ernst, CL, Bellizzi, MJ, Wright, S and Weyand, P. A metabolic basis for impaired muscle force production and neuromuscular compensation during sprint cycling. *American Journal of Physiology: Regulatory, Integrative and Comparative Physiology*, **291:**R1457-64, 2006.

Weyand, P. Sandell, RF, Prime DN, Bundle, MW. Mechanical limits to running speed: set by limb force maximums or stance time minimums? *Journal of Applied Physiology,* in review.

Weyand, P., Smith B, Sandell, R. Assessing the metabolic cost of physical activity: influence of baseline subtrations, submitted to the *Proceedings of the International Society of Engineering and Medicine in Biology*, in review.

Bundle, MW and Weyand P. Metabolism, force application and fatigue during brief, all-out exercise: I. Sprint cycling, in preparation for submission to the *Journal of Physiology*.

Bundle, MW and Weyand P. Metabolism, force application and fatigue during brief, all-out exercise: I. Sprint running, in preparation for submission to the *Journal of Physiology*.

Abstracts/Presentations

Weyand P. Artificial speed from artificial limbs? Texas Scottish Rite Hospital, Dallas TX, 6/2009.

Weyand, P. Biological barriers and locomotor performance limits: what gives with maximum running speeds? Houston Society of Engineering and Medicine in Biology, Abstract submitted 11/2007, Oral presentation, 2/2008.

Robb, R. and Weyand P. Biological barriers to running speeds: force or rate limited? Rice Undergraduate Research Symposium, 2006.

Sandell, R and Weyand P. Mechanical/metabolic limits to human locomotor performance I. Rice Undergraduate Research Symposium, 2007

Prime DN. and Weyand P. Mechanical/metabolic limits to locmotor performance II. Rice Undergraduate Research Symposium.

CONCLUSIONS:

Major conclusions with specific respect to the three objectives in the statement of work for the first grant period as provided in the final report were:

1. All-out locomotor efforts above the maximum intensities that can be supported aerobically cannot be sustained for shorter but not longer durations because: 1) anaerobic metabolism impairs the muscular force production necessary to maintain the intensity of the effort, and 2) impaired muscular force production ultimately compromises the external forces the limbs can apply thereby resulting in the cessation or termination of the effort. The exercise intensity

2. Our results suggest that a two-test protocol similar to that described previously (Bundle et al, 2003) will suffice in determining the anaerobic and aerobic fitness of soldiers. Our results also raise the possibility that this might be accomplished with a single test that approximates the current standard of the Wingate test. Specifically, our results indicating that our anaerobic reserve model accurately describes the losses in power output that occur over the course of the Wingate test suggests a single 30 to 60 s test may provide a full profile of an individual's anaerobic and aerobic fitness. A full conclusion on this latter possibility brought about by our finding s here awaits more comprehensive and detailed investigation.

3. The progressive recruitment of additional motor units during fatiguing exercise occurs in all the major muscles involved in the exercise effort. The latter stages of this process during which maximal volitional recruitment appears to be reached forces the cessation of exercise or a reduction in exercise intensity.

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1. Alexander, RM. Sprinting and endurance for runners and cyclists. *American Journal of Physiology: Regulatory, Integrative and Comparative Physiology,* 290(3):R757.

2. Bundle MW, Hoyt RW and Weyand PG. High speed running performance: a new approach to assessment and prediction. *Journal of Applied Physiology,* 95:1955-1962, 2003.

3. Bundle, MW, Ernst, CL, Bellizzi, MJ, Wright, S and Weyand PG. A metabolic basis for impaired muscle force production and neuromuscular compensation during sprint cycling. *American Journal of Physiology: Regulatory, Integrative and Comparative Physiology*, 291(5):R1457-64, 2006.

4. Weyand, P. Lin, J.E. and M. Bundle. Energetics of high-speed running: integrating classical theory and contemporary observations. *American Journal of Physiology: Regulatory, Integrative and Comparative Physiology*, 290(3): R758-65, 2006.

5. Weyand, P. and M. Bundle. Energetics of high-speed running: integrating classical theory and contemporary observations. *American Journal of Physiology: Regulatory, Integrative and Comparative Physiology*, 288: R956-R965, 2005.