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14. ABSTRACT: The objective of the proposed effort is to develop a brief and accurate method for the simultaneous assessment of anaerobic and aerobic fitness that is practical for both field and laboratory use. We anticipate that a method requiring an assessment period of only a few minutes or less, and two brief, minimally fatiguing efforts is possible. Each subject will undergo established tests to assess their maximal aerobic power and anaerobic power, respectively. Subjects will also complete a series of all-out efforts to establish their performance capabilities for efforts of different durations. Our analysis will focus primarily on two questions. First, we will determine if the relationship between the metabolic power available and all-out performance capabilities is common or dependent upon the fitness level of the individual. Second, we will determine whether the relationship between metabolic power and performance varies with the type of physical activity in which soldiers are engaged. We hypothesize that a single relationship will generalize to: 1) different individuals regardless of fitness level, and 2) to different types of physical activity. The development of a simple, practical and accurate method for assessing metabolic fitness and performance capabilities will provide a number of benefits.

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INTRODUCTION

The objective of the proposed effort is to develop a brief and accurate method for the simultaneous assessment of anaerobic and aerobic fitness that is practical for both field and laboratory use. We anticipate that a method requiring an assessment period of only a few minutes or less, and two brief, minimally fatiguing efforts is possible. Each subject will undergo established tests to assess their maximal aerobic power and anaerobic power, respectively. Subjects will also complete a series of all-out efforts to establish their performance capabilities for efforts of different durations. Our analysis will focus primarily on two questions. First, we will determine if the relationship between the metabolic power available and all-out performance capabilities is common or dependent upon the fitness level of the individual. Second, we will determine whether the relationship between metabolic power and performance varies with the type of physical activity in which soldiers are engaged. We hypothesize that a single relationship will generalize to: 1) different individuals regardless of fitness level, and 2) to different types of physical activity. The development of a simple, practical and accurate method for assessing metabolic fitness and performance capabilities will provide a number of benefits.

The specific tasks identified in the approved statement of work 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 was granted by the HSRRB as of 1/13/2005. Our last report was filed on 10/30/2005. The results reported below have been accomplished between 10/31/2005 and 11/1/2006.

KEY RESEARCH ACCOMPLISHMENTS:

We hypothesized that all-out performance in any mode of exercise engaging a large fraction of the boy's muscle mass could be accurately predicted by our anaerobic reserve model (1,3,4). The model, originally developed for running, postulates that all-out efforts all in a common exponential manner for the maximum burst sprint performance to the maximum intensity that can be supported aerobically as the duration of the effort becomes more prolonged. The hypothesis has the following quantitative form:

$$\text{Perf}(t) = \text{Perf}_{aer} + (\text{Perf}_{mech\ max} - \text{Perf}_{aer}) \bullet e^{(-k \bullet t)} \quad (1)$$

where Perf is expressed as an intensity (i.e., running speed, cycling power, etc) and thus Perf(t) is the power output or running speed maintained for a trial of duration t, $\text{Perf}_{mech\ max}$ is the maximum power output for a trial of 3 seconds, Perf_{aer} is the maximum mechanical power output that can be supported by aerobic metabolism, the quantity $\text{Perf}_{mech\ max} - \text{Perf}_{aer}$ is the anaerobic reserve, e is the base of the natural logarithm, and k is the exponent that describes the decrements in performance occurring with increments in the duration of all-out efforts.

As noted in our last report, we had begun to extend our model to a 2nd mode of exercise that engages a large fraction of the body's musculature, cycle ergometry. We had hypothesized that we would find that the value of the exponent k that describes duration-dependent decrements in performance would be the same for both different individuals regardless of their mechanical and aerobic maxima and for any type of exercise.

We have found that the model and value of k is independent of the fitness level and therefore the absolute values of the maximum mechanical and aerobic exercise intensities of the individual as we had hypothesized. However, contrary to our expectation, we found the value of k does differ across different types of exercises. We found that the value of k for all-out cycling (k = 0.026) was twice that previously identified for running (k = 0.013) because the active muscles apply force for proportions of the total exercise time that are twice as long (i.e. the duty factor) during cycling vs. running (1).

In this last reporting period we have focused on objective three from the statement of work which hypothesizes a mechanistic basis for the general relationship provided by the model. Our model postulates that duration dependent decrements in performance result from a reliance on anaerobic metabolism that induces a progressive impairment of the forces that the active muscles can produce and that the skeleton can apply to the environment. We evaluated this possibility by collecting simultaneous ground reaction force and electromyography (EMG) data during brief, all-out treadmill running for 6 subjects running at speeds above the maximums that they could support aerobically as proposed in our application.

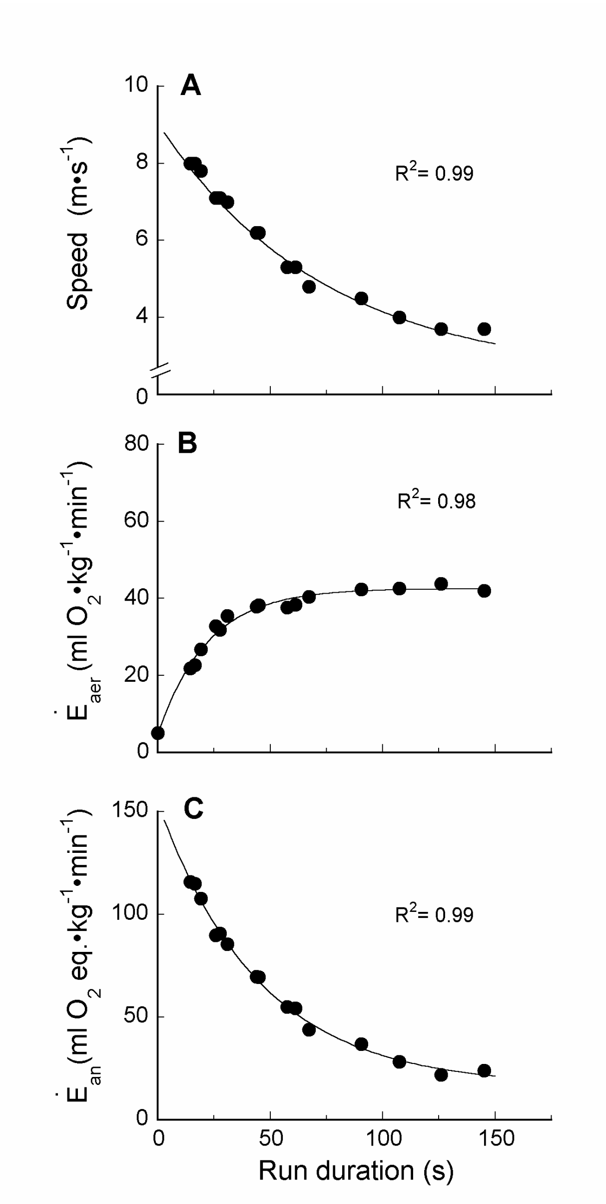

Figure 1. Speed (A) and rates of aerobic (B) and anaerobic energy release (C) during all-out running efforts of different durations for a male subject.

For background and orientation to the running experiments, representative data from a single subject is presented above in Figure 1 and the accuracy of the model for running (with k = 0.013) is presented in Figure 2 (5).

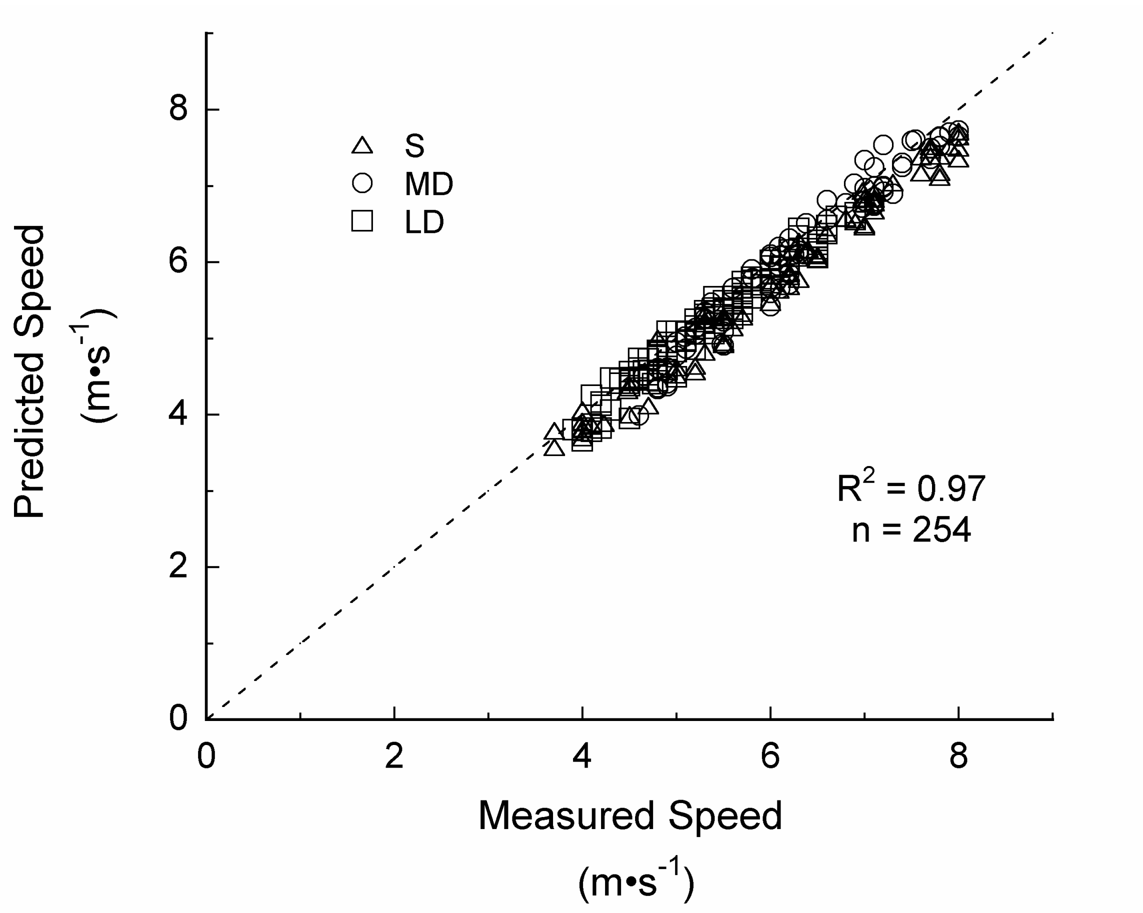

Figure 2. The speeds measured during all-out runs of different durations vs. those predicted by our anaerobic reserve model per equation one above (5). Note we have not yet performed the equivalent analysis to that above with our newly acquired running data.

Our model postulates that the mechanistic basis for the performance decrements observed as the duration of all-out exercise becomes more prolonged is metabolic. We specifically expected that the reliance on anaerobic metabolism at exercise intensities above the maximums that could be supported aerobically would impair muscle force production. We further anticipated that impairments in muscle force production would induce the compensatory recruitment of additional muscle so that the musculoskeletal system would be able to continue to generate and apply the required force to the ground. In accordance with general practice and our application we assessed relative recruitment and force impairment indirectly using surface electromyography.

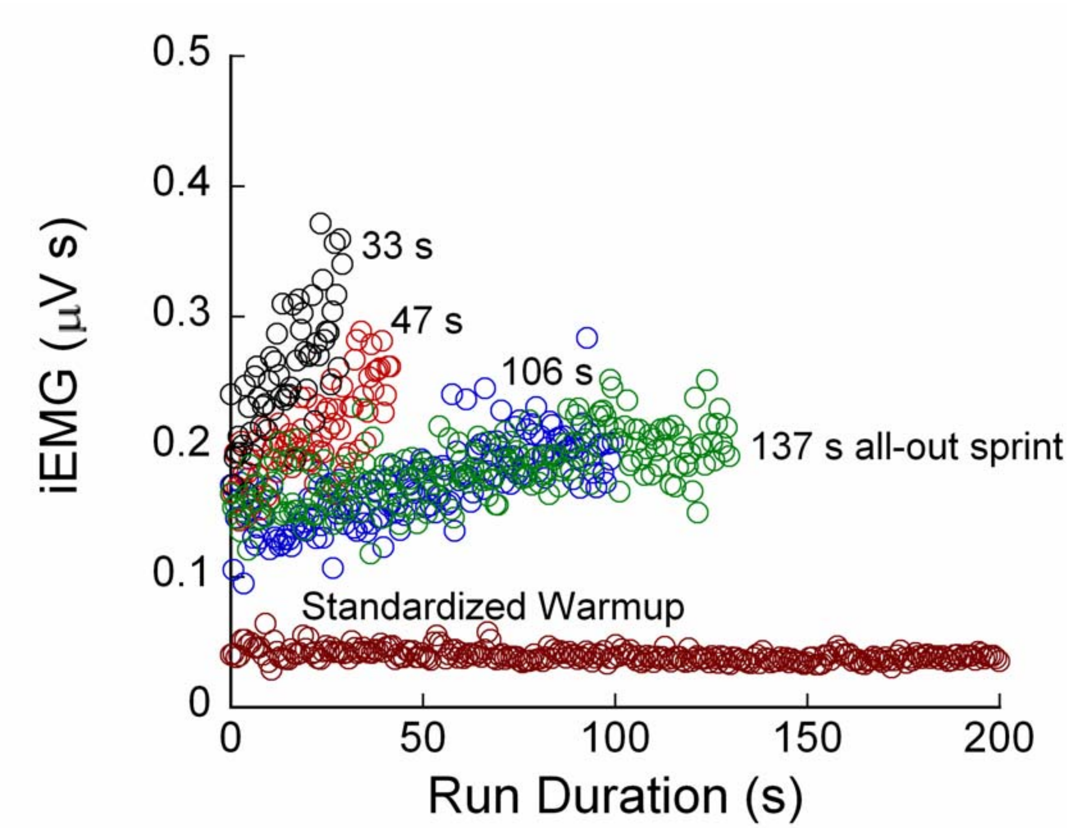

Figure 3. The rectified integrated surface EMG signal (iEMG) from the biceps femoris of one subject during all-out treadmill runs of different durations at different intensities or speeds above the aerobic maximum. The surface iEMG activity increased throughout all of the all-out runs. In contrast, during submaximal running, the iEMG signals from the biceps femoris remained constant over time.

We had two specific expectations. First, we expected that at any exercise intensity above the maximum that could be supported aerobically, the muscle recruitment and therefore surface EMG signals would increase throughout the all-out trial. This was based on our belief that the reliance on anaerobic metabolism would progressively impair muscle force production. Second, we expected that the rates of increase in surface EMG signals would be greater for those trials conducted at greater exercise intensities. This expectation was based on the recognition that greater exercise intensities would require greater muscle and ground/pedal forces, and therefore would have a correspondingly greater reliance on anaerobic metabolism for force production.

During the past reporting period, we collected simultaneous ground reaction force data from our custom force treadmill and surface EMG data from 5 muscles: vastus lateralis, vastus medialis, biceps femoris, and medial and lateral gastrocnemius muscles. These data were taken on 6 volunteer subjects who were tested for the maximum sprinting speeds, their maximum aerobic power, and the maximum speeds supported by their aerobic power. These subjects also completed an average of 15 all-out runs at speeds greater than their aerobic maximums. We collected simultaneous ground reaction force and EMG data for the duration of all of these trials (n= 6 subjects x 15 trials each = 90 total all-out trials).

As can be seen in Figure 3, our measurements conformed to our expectations during all-out treadmill running for the subject and biceps femoris muscle shown. Patterns for other muscles and subjects thus far analyzed have also conformed closely to the patterns present in Figure 3. Thus, in accordance with expectations, the surface iEMG signals from all the muscles sampled thus far have increased throughout the duration of each trial. Additionally, the rates of increase in the EMG signals were consistently greater during those trials conducted at greater intensities, and therefore with greater ground and muscle force requirements as well as a greater reliance on anaerobic metabolism for force production. The consistency with which rates of iEMG increase paralleled running speeds and therefore “anaerobic” force requirements is illustrated in Figure 4.

Analysis of the EMG data for these trials remains in progress. We also need to reduce and analyze the simultaneous ground force data taken during these trials in the coming year.

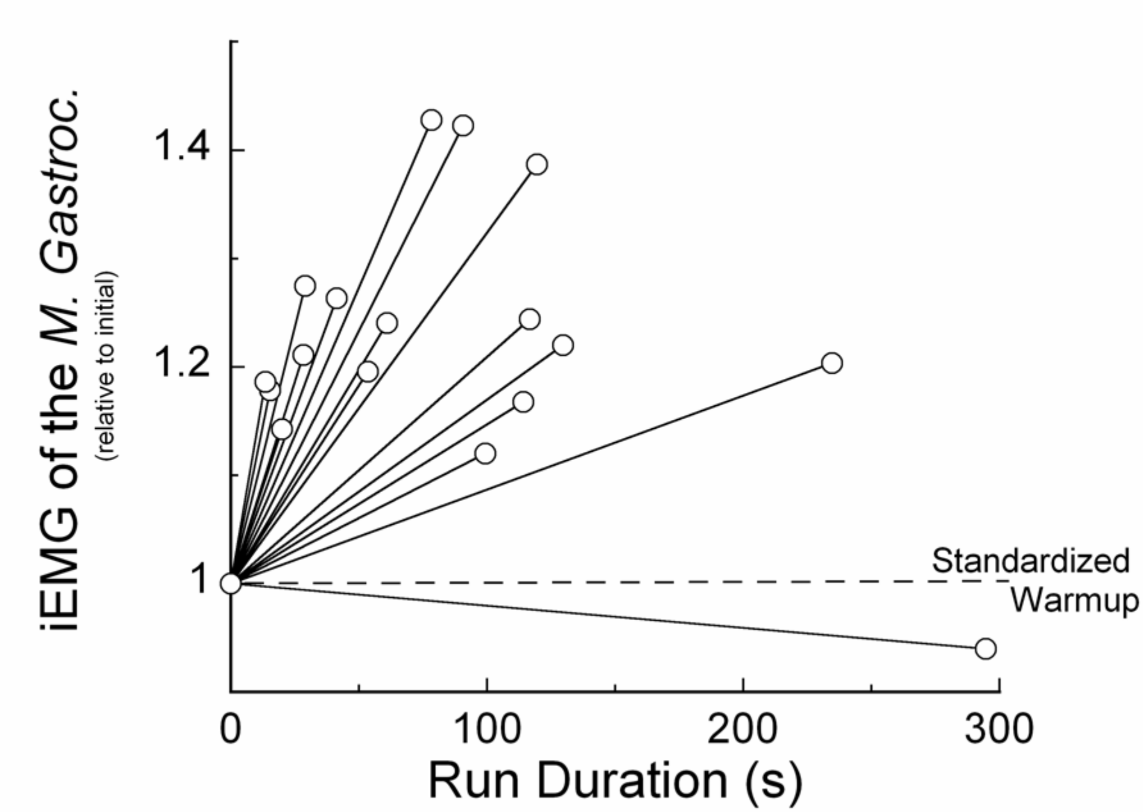

Figure 4. Surface iEMG signals from the biceps femoris of one subject during all 16 of the all-our running trials this subject completed. Increases in the iEMG signal from the beginning to the end of the trial were more rapid for those trials conducted at faster speeds. All increases are plotted relative to the average value from the initial 5 contractions (assigned a value of 1.0 for all trials). During submaximal running at a speed below the maximum that this subject could support aerobically, the iEMG signal remained constant or perhaps decreased slightly over the course of the 5 minute run.

To further assess whether a mechanistic link between a reliance on anaerobic metabolism for force production and an impairment of muscle force production, we similarly analyzed the cycling EMG-force data taken previously and from which representative samples were presented in our last report.

We expected that the threshold at which compensatory recruitment occurred would similarly correspond to maximal pedal forces that could be supported aerobically during both cycling and running even though the absolute muscle and external (i.e. ground or pedal) forces would differ markedly.

REPORTABLE OUTCOMES:

In our prior report, we noted that we had set up our custom force treadmill, software, and filtering techniques for the treadmill force signals. In this past reporting period, we performed additional troubleshooting to maximize the fidelity of the force signals from our treadmill. We also adjusted motor parameters to maximize treadmill performance during higher speed running. Treadmill performance was evaluated using a mechanical device (an asymmetrically weighted tire) that simulates the forces applied during high-speed running. We have also written custom software to reduce and analyze the treadmill force and surface EMG data. Both variables are collected at frequencies above 200 Hz.

In this reporting period, we have also collected simultaneous ground reaction force and EMG data from 6 subjects during treadmill running. This typically involved 5 sessions and approximately 25 trials per subject. We have also moved forward with the analysis of the original cycling force and EMG data presented in our last report.

Finally, please note that due to the delay between this award becoming active and the approval of the protocol by the IRB, the experiments were not begun until many months after the award's commencement date (10/2004). Accordingly, we contacted the Army Contracting Officer to request a one year no cost extension to complete the work in the coming year. This extension has been granted. We anticipate filing our final report next year.

Reportable outcomes here are in the form of the original data collected and presented above in this report. Per our application, we have collected an extensive set of simultaneous EMG and ground reaction force data during all-out running. We have also recently published cycling EMG and force data (3). The line of work supported by this grant was featured in an editorial focus piece (1) in the *American Journal of Physiology: Regulatory, Integrative and Comparative Physiology*.

CONCLUSIONS:

Preliminary conclusions from the past reporting period are as follows:

1. All-out locomotor efforts above the maximum intensities that can be supported aerobically are non-steady state exercises with respect to muscle recruitment.
2. Increases in the rates of compensatory recruitment during all-out exercise are greater for those efforts taking place at greater intensities and relying more heavily on anaerobic metabolism for force production.
3. Muscle force production in vivo is impaired by a reliance on anaerobic metabolism for force production.
4. Impairments in muscle force production resulting from a reliance on anaerobic metabolism generalize to exercises with different whole-body and muscle mechanics such as cycling and running.

REFERENCES:

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.

APPENDICES:

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