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EFFECTS ON MOTOR UNIT POTENTIATION AND GROUND REACTION FORCE FROM TREADMILL EXERCISE

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ABSTRACT

Exercise countermeasures in long duration space flight have primarily been focused on two modalities, the treadmill and bicycle ergometer. Their use in space flight has been shown to offset the deleterious effects of disuse resulting from habituation in a weightless environment. Thus, muscle atrophy, osteoporosis and neuromuscular inefficiency -- physiological consequences from prolonged exposure to microgravity -- can be controlled by use of these modalities and their proper exercise regimen. Because muscular atrophy has been most significant in the posterior calf muscles and muscles of the thigh, the use of exercise modalities that concentrate on the musculature of the lower body is warranted. The treadmill and bicycle ergometer both require similar musculature in the activities of running and cycling although the sequence of their actions and intensity of their recruitment patterns may vary. Also, the reaction between the surface of a treadmill and the lower segments in ground reaction force (GRF) measures differ from pedal to foot reactions in cycling, running GRF's being far greater than those measured in cycling. Motor unit potentiation (MUP) as measured by electromyography (EMG) is indicative of muscular actions and may be greater where stress from increased GRF is imposed. Therefore, greater MUP from treadmill exercise may be expected due to the greater GRF generated in running over cycling. This study was conducted to analyze the characteristics of MUP and GRF in treadmill exercise at the inclines of 0, 5.5 and 11 % with conjuctive speeds of 7.5, 6, and 5 MPH respectively. These speeds and corresponding inclines were set to provide equivalient physiological workloads at 12.5 METS. EMG recordings were taken from the rectus femoris and gastrocnemius of the right leg from 5 subjects. Simultaneous GRF recordings were obtained from a Delmar Avionic treadmill rigged with load cells. Measures for MUP and GRF were taken over a period containing 10 strides at steady pace. Results of ANOVA revealed no significant differences between MUP of the rectus femoris at different speed/incline settings. The same was true for the gastrocnemius. Significant differences were found between MUP of the rectus femoris and gastrocnemius at all treadmill settings ($p<.01$), with the MUP of the gastrocnemius being greater. No significant relationships between MUP of the thigh and GRF, and MUP of the calf and GRF were found ($r=.097$ and $r=-.31$ respectively). Significant differences were found among GRF with 11% grade higher than 0% ($p<.05$) and 5.5% over 0% ($p<.01$). It was concluded that the gastrocnemius was more evident in EMG activity in all speed/incline settings over the rectus femoris, and that inclines from 5.5-11% produced a greater GRF's over 0%. Recommendations for future studies was made.

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INTRODUCTION

Long duration space flight has a profound effect on the human musculoskeletal and neuromuscular systems. Reported consequences from prolonged habituation in a microgravitational environment include muscular atrophy (2,4,5,7,12), bone loss (1,11,17,18) and decrements in neuromuscular performance (2,9,10,12,14,20).

These physiologic problems are evident particularly in the lower body segments and arise from disuse(1,14,15). The absence of weight-bearing stresses to musculature and their supporting structures, as experienced in 1 g, lead to these maladies (1,11,15,16). Because the use of lower body segments in locomotion is no longer a requisite for ambulation, these structures are virtually devoid of volitional input. This creates in essence, a neuromuscular shunt, and a situation similar to what is observed in denervated muscle occurs (3,6).

Exercise countermeasures have been reported to have some degree of efficacy in offsetting the debilitating effects of weightlessness (4,11,12,14,20). In particular, the exercise modalitites of primary use in manned space flights have been the treadmill and bicycle ergometer since these modalities concentrate their effort-requirements to the lower body (11,15,16).

In previous studies, space flight has been shown to have an atrophying effect on muscles of the posterior calf (4,19,20) as well as the thighs and buttocks (19). Muscle strength deficits from post-flight studies have been observed in dynomometric measures of isokinetic force production of the lower limbs (14,20). Electromyographic (EMG) studies showed that muscular efficiency and fatigue onset was increased after 1-14 days in space, and shifts to higher frequencies in power spectrum analysis following flights of longer than 2 weeks duration, implied muscle deterioration (12). Studies like these have supported the postulates concerning disuse atrophy, osteoporosis and neuromuscular degradation.

Measurements comparing ground reaction or vertical forces of cycling and running have shown that ground reaction forces are greater in running than in cycling (1,15,16). Reasons for this difference center on factors of gravitational force, or forces imposed on the body and its supporting appendages. Basically, locomotion by running involves a great amount of decelerative or negative forces which provide for the storage of elastic energy to be released in subsequent positive muscular contractions (13). This was termed the stretch-shortening cycle by Komi (8) and hints at the existence of eccentric loading in phases of human locomotion (eg. running) which may be absent in non-weight bearing activities (13). Therefore, the greater reaction forces between body segments and surface impact from the effects of gravity, the greater the requirements for muscular activity. Subsequently, it is the increased ground reaction forces that provides the implication of greater muscular activity involved in running over cycling.

The purpose of this study was to:

1. make a basic 1 g analysis of motor unit potentiation and ground reaction force during treadmill running at different speeds and inclines.
2. study any relationships between motor unit potentiation and ground reaction force during treadmill running at different speeds and inclines.
3. establish a means for assessment of individual force/muscle activation characteristics for implementation of protocol to other studies, to include those for training/testing in a weightless environment.

REVIEW

Motor unit potentiation.

The temperosopatial aspects governing human movement are derived from the functioning of the basic components of the integrated neural and muscular systems. Together these systems comprise the operative element, the motor unit. It is the motor unit, when activated via an electrochemical sequence that controls muscular contractions and subsequent limb movement. The force and speed at which limb movements occur are dictated by several factors as follows:

1. the number of motor units recruited.
2. the frequency of firing of motor units.
3. the synchrony of motor unit firing.
4. the pattern of motor unit recruitment.
5. the type of motor units activated.
6. the inhibition of antagonist motor units.

These factors are applicable as determinants of the amount muscular activity produced during running and cycling.

EMG is a means by which the electromechanical dynamics of the neuromuscular system can be measured. Activation of muscular contractions are measured by EMG as electrical current is generated from the difference in potential sources of a dipole. The potential differences at each pole reflect the electrical activity to ensue, and the term motor unit potentiation is used to characterize this.

Ground reaction force.

Forces that the body exerts against the earth's surface in movement, in line with Newton's third law, can be measured by low frequency output from piezoelectric sensors built into load cells. Changes in the forces exerted against the

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running surface of the treadmill are transduced into electric signals which can be calibrated to units of G force.

Often, ground reaction forces are similarly termed vertical or transient forces as the line of gravity is vertical and transmitted along the longitudinal axes of bone structures (transient) in upright ambulation.

METHODS

Subjects were selected from among volunteers who were screened for CHD, were less than 40 years of age, had a completed Air Force Class III physical examination, and were familiar with treadmill exercise (N = 5). Following a complete orientation, subjects signed an informed consent document.

Preparation of the subjects for EMG recording, entailed the use of alcohol prep pads to cleanse and abrade the skin for placement of surface electrodes. The skin was rubbed until it became erythromatous and has an electrical resistance less than 10,000 ohms.

The rectus femoris and gastrocnemius of the right leg were prepared for electrode placement. Prior to placement of the electrodes, a measurement was taken from the point of origin of each muscle to its insertion with the midpoint cited as the point of innervation. Two Ag-AgCl electrodes were placed on either side of this point so that their centers were 4 cm apart. Leads from these electrodes were inserted into a signal conditioner worn at the waist of the subject. The input EMG signals were amplified and transmitted by infrared telemetry to a signal receiver capable of receiving simultaneous signals. These signals were transferred via BNC connection to a Compaq 40 MB hard disk computer for A/D conversion and storage for later analysis.

Ground reaction forces were recorded from four load cell transducers located under the belt of a Delmar Avionics motor-driven treadmill. Analog signals were sent via hardwire BNC connection to the Compaq computer for A/D conversion and storage for future analysis.

Two signal receivers were placed on the wall on the side of the treadmill such that the field of signal acceptance would be perpendicular to the emitted signal.

Each subject was required to perform treadmill running in one session at three different speeds and inclines. Following a warm-up period including stretching exercises and 4 minutes of low intensity treadmill running, the treadmill speed was randomly (as respects order) increased to settings of 5, 6 and 7.5 MPH. These speeds were set conjunctively with grades of 11, 5.5 and 0 % respectively. These speeds and grades (inclines) were selected to represent a physiological equivalency in workload at 12.5 METS (1 MET = VO2 of 3.5 mlO2/kg/min at rest).

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The subjects were instructed to maintain pace at 1-2 minute intervals at the prescribed speeds and inclines such that EMG and ground reaction forces could be taken for a segment of 10 strides.

After completion of the exercise, a cool-down period of 5 minutes was administered and consisted of low intensity walking at a 0% grade. This was followed by a 10 minute recovery period with the subject in a seated position.

<u>Analysis.</u>

Analysis of the raw EMG was performed by integration, and averaged over the ensemble recordings for the 10 strides to produce a mean value for motor unit potentiation.

Measures of ground reaction force was analyzed for the landing-support-takeoff phase of the running stride. An ensemble average of the G force was calculated over 10 strides.

Averaged values for motor unit potentiation and ground reaction forces were compared intersubjectly to note differences between variables in prescribed speeds and inclines of the treadmill. Correlations for motor unit potentiation and ground reaction force were made to analyze relationships between the two variables.

RESULTS

The results of the study are contained in Table 1, and a sample recording of G forces and EMG shown in full wave rectified form are shown in Figure 1.

Results from ANOVA showed that there were no significant differences in motor unit potentiation of the quadriceps at all speeds and incline settings ($p<.05$). The same was found to be the case in differences between motor unit potentiation of the gastrocnemius at the various speed and incline settings. There was a significant difference between motor unit potentiation of the quadriceps and gastrocnemius at all speeds and incline settings ($p<.01$), the mean integrated EMG (IEMG) being greater than quadricep IEMG. Significant differences existed in ground reaction forces [$F(2,12)=12.52; p<.01$]. In post-priori comparison t tests, ground reaction forces generated at 5.5% grade and 6 MPH speed, and 11% grade and 5 MPH speed, were greater than at 0% grade and 7.5 MPH speed ($p<.01$ and $p<.05$ respectively). Ground reaction forces between 11%/5 MPH and 5.5%/6 MPH showed forces to be slightly higher at 5.5%/6 MPH, however the difference was not significant ($p<.05$).

The correlation between motor unit potentiation of the quadriceps and ground reaction forces was not significant ($r=.097$), nor was the correlation between gastrocnemius motor unit potentiation and ground reaction force ($r=-.31$). This

TABLE 1. RESULTS OF TREADMILL RUNNING ON MOTOR UNIT POTENTIATION (MUP) AND GROUND REACTION FORCE (GRF) FOR DIFFERENT TREADMILL (TM) SPEEDS AND GRADES. VALUES ARE MEANS (N = 5).

TM (MPH/%)	MUP (uVs)			GRF (G)
Speed/ incline	Rectus femoris	Gastroc- nemius	TOTAL	Touchdown/ takeoff
5 / 11	166.164	372.438	538.602	2.016
6 / 5.5	203.838	302.598	506.436	2.104
7.5 / 0	226.968	344.258	571.226	1.816

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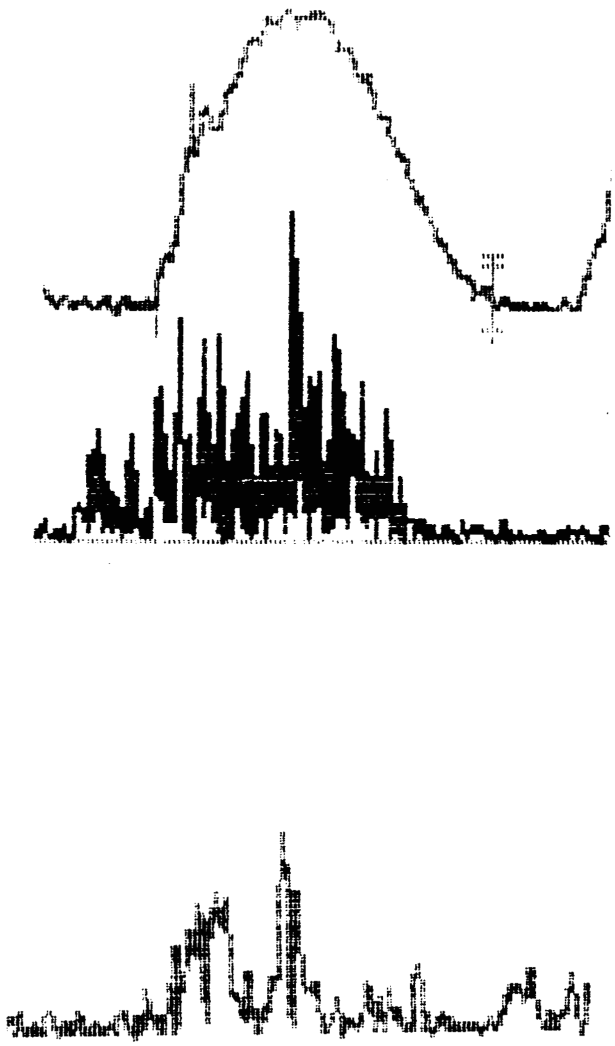

Figure 1. Example from one subject for (a) force recording and full wave rectified EMG recording for (b) the gastocnemius and (c) rectus femoris at 11 % grade and 5 MPH treadmill setting.

was for all speed and incline settings combined.

CONCLUSION

The fact that impact or collision forces exist between the surface of the treadmill and the feet of the exerciser, a vertical force is transmitted along the longitudinal axes of the bone structures. As long as this force is present, the resulting transarticular reaction forces, particularly at the talofibular/tibial and femorotibial surfaces, will require added supporting contractions of the surrounding musculature for joint stabilization. The demands imposed on the musculature of the thigh in knee stability and of the shank in ankle stability may be increased as the reaction forces become greater due to changes in speed and incline. This was not found to be the case in this study, as no significant differences were found between EMG activities of the rectus femoris at all speeds and inclines. The same was true for the gastocnemius. Also, no correlations were found between ground reaction forces and motor unit potentiation of either the rectus femoris or gastrocnemius. Significant differences were found between potentiation of the gastrocnemius and rectus femoris at all speeds and inclines which showed that the calves are more active relative to the quadriceps in all cases analyzed in this study.

Because running requires the individual to be airborne in between strides, the resulting G forces upon impact will be greater than in walking. That increases in speed require a greater pushoff in the takeoff phase, resulting in greater airborne time, the ensuing impact may be thought to be greater, however the contrary was found to be true from the results of this study. Greater G forces were found at inclines of 11% and 5.5% over horizontal running at speeds of 5 and 6 MPH respectively versus the greater speed of 7.5 MPH at 0% grade. This was attributed to the greater horizontal impedence necessary to be exerted against the belt for pushoff in the horizontal direction. This detracts from the vertical pushoff force that was measured by the load cell instrumentation.

Greater EMG activity of the gastrocnemius at 11% grade may be attributed to the need for more forefoot running, therefore eliciting a greater stretch on the calf muscles and resulting in a stronger muscular impulse. This supports Komi's (8) assertion of eccentric factors contributing to the stretch-shortening reflex (stronger ensuing positive contraction) in running. It was interesting to note that the potentiation of the gastrocnemius at 5.5% was lower than both the 11% and 0% grades. This would show that either increased speed or inclines at 11% or higher may be capable of eliciting higher EMG responses than at lesser speeds at mid-range grades -- perhaps 1-10%.

Ground reaction forces were greater at inclines of 11%

and 5.5% over 0%, however the higher values at 5.5% over 11% indicated that there may be an optimal grade for promoting higher G forces in running at moderate speeds.

In summary, the results of this study revealed that speed and incline variation in treadmill exercise at 1 g can effect ground reaction force such that higher G forces can be produced at grades ranging from 5.5 to 11%. Motor unit potentiation of the quadriceps and gastrocnemius were found to be virtually unaffected by speed and incline variations as respects significant difference between the changes in these variables, although trends may exist between increased speed/incline and increased EMG activity, but this was not analyzed in this study.

Inclines may have no effect in a 0 g environment, however, restraint systems to treadmill exercises can be set such that forward inclinations in body lean can be made to produce resultant forces to bring about greater ground reaction forces. Increased G forces imposed by treadmill parameters imply greater transient forces to long bones involved in locomotion and therefore greater benefit to the structural integrity of bone tissue.

The study also revealed that physiological workload equivalencies, as set by MET requirements, are not paralleled by biomechanical and neuromuscular factors in actual exercise on the treadmill. Hence exercise countermeasures in space flight, where muscle, bone and neuromuscular considerations are concerned necessitate monitoring of the effect of the exercise regimens and modalities according to the response of the human body to the imposed demands of exercise by EMG and force transduction.

As this serves as a pilot study, the results lead to the following recommendations:

1. A basic 1 g comparison between the effects on motor unit potentiation (MUP) and ground reaction force (GRF) in treadmill and bicycle ergometer exercise.
2. The effects of prolonged treadmill running on bone density versus the same in bicycle ergometer exercise.
3. An analysis of the muscular torques and transarticular forces about the knee and ankle in treadmill running by means of optoelectrical data collection and anthropomorphic modeling.
4. The effects of treadmill running at various body inclinations and speeds on MUP and GRF in 0 gravity.
5. The differences between total body standing resistive exercises and treadmill running on MUP, GRF, muscle torques, transarticular reaction force and bone density.
6. The effects on MUP and GRF in decline treadmill running: an analysis of eccentric contractions in locomotion.
7. The effects of running shoes on MUP and GRF at different speeds and inclines in treadmill running.
8. The relationships between increasing speed/incline on MUP and GRF.

9. The relationships between MUP and physiological measures of energy expenditure (ie. VO2 and kcal).

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