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Changes in Human Energetics Following Acute Head-Down-Tilt-Bed-Rest

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ABSTRACT

During spaceflight, humans experience several physiological adjustments. Among these changes there is an energy imbalance that results in the loss of body mass in astronauts. The purpose of this study was to determine if energy expenditure decreased after acute Head-Down-Tilt-Bed-Rest (HDTBR). This decrease in energy expenditure is a potential contributor to the energy imbalance we see, and is likely a result of the decreased muscle activation that occurs in a microgravity environment. This study used acute HDTBR as a ground-based model of spaceflight, which mimicked the decreased muscle activation. We measured resting metabolic rate (RMR) and sub-maximal energy expenditure in seven male subjects before, after and five days after HDTBR. Subjects' RMR showed no change after experiencing acute HDTBR ($p=0.79$), and sub-maximal energy expenditure also did not change after acute HDTBR ($p=0.98$). These results indicate that acute HDTBR has little to no effect on energy expenditure. More research needs to be done to determine if microgravity has an effect on energy expenditure in either the short or long term.

INTRODUCTION

During spaceflight, humans experience several physiological adjustments that may affect the astronauts' well-being. Among these changes, there is a fluid shift, whereby blood and other bodily fluids are re-distributed away from the legs and are more evenly distributed throughout the body (Williams et al., 2009). There is also a marked decrease in both muscle activation and the cross-sectional area of muscles, especially in postural muscles (LeBlanc et al., 2000) which results in a decrease in body mass (Stein, 2013). The decrease in body mass is the result of an alteration in an individual's energy balance i.e. the difference between energy intake and energy expenditure. When energy expenditure is decreased in humans (due to decreased muscle activation in this case) the body attempts to maintain an "ideal" energy balance (adaptive thermogenesis) by decreasing energy intake (Major et al., 2007). While astronauts experience an expected decrease in their energy expenditure, the dietary intake aboard the International Space Station (ISS) is still only ~80% of the recommended intake given the astronauts' new predicted energy expenditure for space (Stein, 2013). This could be due to a couple of reasons. One possibility would be that there is less energy expended in space than originally theorized, this might contribute to why energy intake is lower than originally predicted. Another possible explanation would be that nausea and psychological stress lower the appetite of the astronaut. It could also be a mix of the two. In order to determine the extent to which spaceflight affects energy expenditure, we can use ground-based models to isolate the physiological parameters of spaceflight from the nausea and psychological stress caused in a microgravity environment. Head-Down-Tilt-Bed-Rest (HDTBR) is currently the best ground-based model of spaceflight to be developed (Pavy-Le Traon et al., 2007). While in HDTBR, the subject lays either supine or prone with the bed tilted 6 degrees, so that his/her feet are above his/her head. Simply the act of lying down causes decreased activation of muscles. By positioning the feet above the head in HDTBR, the body also undergoes a fluid shift similar to that of a microgravity environment. While the physiological changes of muscular atrophy, physical inactivity, and fluid volume shifts are mimicked, the psychological effects of spaceflight are not, and the subject experiences no nausea. This approach allows us to determine whether simulated microgravity alone has an effect on energy expenditure at rest and during exercise.

Research is currently being conducted at the University of Colorado at Boulder that is exploring the effect of acute (four day) HDTBR on hemoglobin mass and blood volume in human subjects. This larger study presented the opportunity to observe changes in resting metabolic rate (RMR, or energy expenditure at rest) and energy expenditure during sub-maximal exercise, before and after HDTBR, allowing us to investigate the effects of HDTBR on energy expenditure. We hypothesized that after four days of HDTBR, RMR, and sub-maximal energy expenditure would be decreased.

Though this experiment utilized only short term HDTBR, this information is still important as spaceflight continues to become more privatized in upcoming years. As individuals will be making shorter trips to space, this information will be relevant in counteracting the effects of acute microgravity exposure and allow for a smoother transition from microgravity to gravity. If it is found that energy expenditure during exercise and rest is affected by simulated microgravity, this study could give rise to longer longitudinal studies, and help in maintaining energy balance during extended space trips. This study also has other applications that could be of import, such as a better understanding of metabolic responses to short term and prolonged rest for individuals on Earth.

METHODS

General Study Design

Seven healthy, recreationally active young men (ages 18-28) were recruited for this short term HDTBR study. Subjects underwent screening to determine if the subject was healthy enough to complete the protocol as well as ensure that there were no confounding factors to influence the experiment. More information on the screening criteria can be obtained elsewhere (Ryan et. al., 2016). After initial screening for general health and obtaining informed consent, they had a one-week period of sleeping in consistent eight-hour intervals and forgoing caffeine, alcohol and medications to aide in eliminating confounding variables for the study. During this week each subject wore an Actiwatch® that determined if the subject was actually getting the eight hours of sleep they were assigned, to ensure that sleep deprivation did not alter the results. .

The subjects arrived at the lab during the evening of day 0, five hours prior to their prescribed bedtime, and slept in the lab that night in the horizontal, un-tilted position. The next morning, on day 1, after waking from eight hours of sleep, they ate an energy bar and were allowed to relax for two hours before heading down the hall to determine body mass, RMR, submaximal exercise energy expenditure (GXT; see *GXT Procedure*) and VO_2 max. After completion of these procedures, the subjects ate a breakfast of predetermined calories as described below. The subject then began the -6° head-down tilt bed rest period (HDTBR).

The subjects remained in HDTBR from midday on day 1 until the morning of day 5 for a total of 4 days in HDT. Apart from ~5 minutes per day in the seated position for defecation, they remained in the HDT position at all times. For urination they used a portable urinal container while remaining in the HDT position. They were provided 3 meals and a snack each day, with the calorie content per day determined as 1.2 x RMR, with substrate percentages at ~55% carbs,

~15% protein and ~30% fat. They completed computer-based performance tests daily to examine changes in cognitive performance as a result of HDT, and maintained an 8 hour sleep schedule.

On the morning of day 5, after being woken at their habitual wake time and eating an energy bar, the subjects slowly progressed from sitting to walking to prevent dizziness and fainting. Two hours from their snack time they went down the hall again to determine body mass, RMR, submaximal energy expenditure and VO_2 max. After completion of these tests, subjects went home for a five day period and were instructed to eat their habitual (at home) diet and maintain their imposed eight-hour sleep schedule. They were also asked to refrain from caffeine, alcohol and medications for at least two days prior to their final visit.

The subjects returned to the lab on day 10 within an hour of their habitual wake-time following an overnight fast, and were provided an energy bar. After waiting two hours we once again determined body mass, RMR, submaximal energy expenditure and VO_2 max.

Graded Exercise Test (GXT) procedure

Oxygen consumption (VO_2), carbon dioxide production (VCO_2), respiratory rate, tidal volume, Ventilatory expiration (V_E), and respiratory exchange ratio (RER) were measured every 15s using the open circuit indirect calorimetry system (ParvoMedics TrueOne® 2400, Sandy, UT, USA). The pneumotachometer was calibrated using a 3L calibration syringe at flow rates between 75 and 275 L/min. The gas analyzers were calibrated with room air and with a standard gas, with the concentration of CO_2 being 4.139% and O_2 being 16.06%.

Before beginning the GXT, the subjects rested for 10 minutes. We measured the subjects' expired air during the last 5 minutes of the 10 minute resting period, and analyzed data for the last 2 minutes of the resting period to determine the subject's RMR. After this resting period the subject began cycling at a workload of 50 watts, with the intensity level rising every 3 minutes by 30 watts until the subject reached a rating of perceived exertion of 16 (on a scale from 6-20). VO_2 was analyzed during the last minute of every stage with the assumption that the subject has reached a steady state VO_2 after two minutes at that workload.

Data Analysis

Energy expenditure and substrate utilization were determined from VO_2 and the caloric equivalents given from RER. In addition to measuring VO_2 and energy expenditure at rest, we measured VO_2 and energy expenditure for all subjects at workloads of 50W, 80W and 110W, and excluded the data from higher powers – so that the energy was provided by predominantly aerobic sources. The slope and intercept of VO_2 vs. workload and energy expenditure vs workload for each subject were analyzed at these workloads. This was done on days 1, 5 and 10 to determine if there was a change in economy (i.e. using a different amount of energy in calories for the same amount of work done in the same environment).

Statistical Analysis

Statistical analyses were performed using Statistical Package for the Social Sciences (version 22, SPSS Inc., Chicago, IL, USA). We performed linear mixed model statistical analyses to examine changes in dependent variables across time. P-values less than 0.05 were considered statistically significant.

RESULTS

Resting metabolic rate

Figure 1 shown below shows resting oxygen consumption (VO_2) measurements in subjects on day one, day five and day ten. There was no change between the three visits ($p=0.65$). *Figure 2* gives the respiratory exchange ratio (RER) in subjects on day one, day five and day ten. We see that the R value did not change over the three visits ($p=0.33$), meaning that the substrate utilized for energy did not change. *Figure 3* shows energy expenditure at rest over the three visits, determined from the measurements of VO_2 and RER. This did not change ($p=0.79$), which stands to reason if neither VO_2 nor RMR changed. Resting energy expenditure had means and standard deviations of 1.89 ± 0.20 kcal*min^{-1} for day one, 1.82 ± 0.29 kcal*min^{-1} for day five and 1.90 ± 0.28 kcal*min^{-1} for day ten.

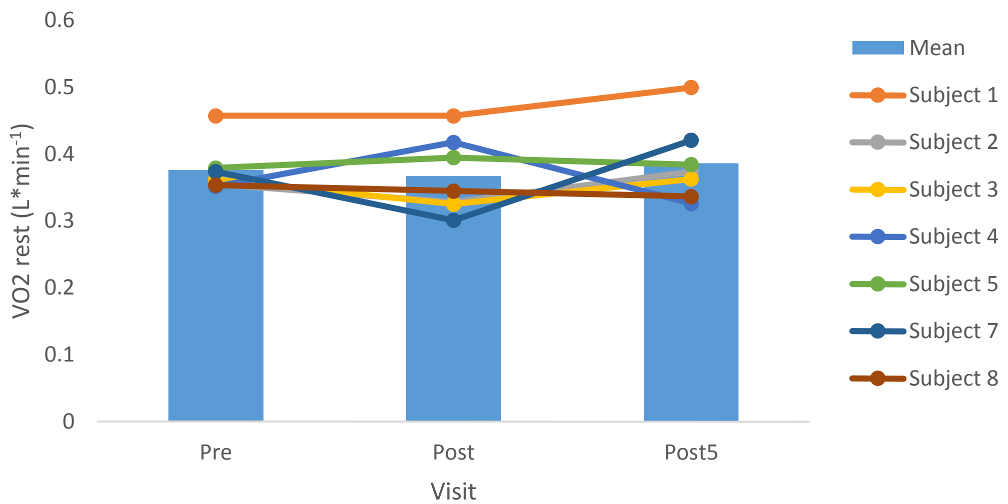

Figure 1: Subjects' (n=7) resting VO2 measured two hours after eating, using indirect calorimetry. Individual values for days 1 (pre), 5 (post) and 10 (post5) are plotted via line graph, with the group mean plotted via the bar graph. P-value = 0.65.

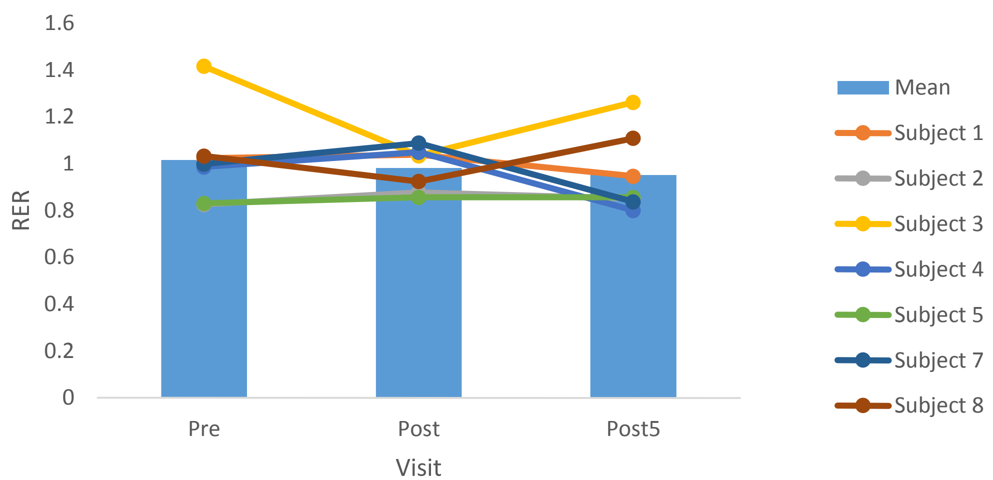

Figure 2: Subjects' (n=7) resting RER measured two hours after eating, using indirect calorimetry. Individual values for days 1 (pre), 5 (post) and 10 (post5) is plotted via line graph, with the group mean plotted via the bar graph. P-value = 0.33.

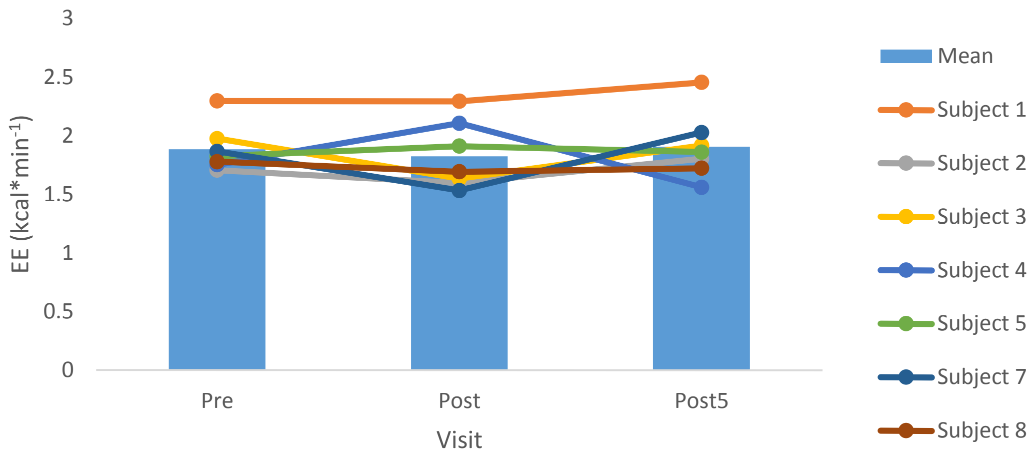

Figure 3: Subjects' (n=7) resting Energy Expenditure (EE) determined from resting VO2 and RER. Individual values for days 1 (pre), 5 (post) and 10 (post5) is plotted via line graph, with the group mean plotted via the bar graph. P-value = 0.798.

Sub-maximal Energy Expenditure

Sub-maximal energy expenditure also did not show statistically significant differences after HDTBR. *Figure 4* below shows measurements for both VO_2 slope and VO_2 intercept, taken to determine energy expenditure in kcal*min^{-1}. Neither VO_2 slope (p=0.83) nor VO_2 intercept (p=0.87) shows statically significant changes after HTDBR. *Figure 5* below shows the measurements for both energy expenditure slope and energy expenditure intercept, to illustrate if there was a difference in the subjects economy before and after HDTBR. There was not, as neither energy expenditure slope (p=0.67) and energy expenditure intercept (p=0.98) had p-values below p=0.05. Sub-maximal VO_2, which was not graphed below, had a p-value of 0.97, and sub-maximal energy expenditure, which was also not graphed, had a p-value of 0.98. Although these parameters are not graphed, they were very linear. This is why the slope and intercept of each parameter was analyzed.

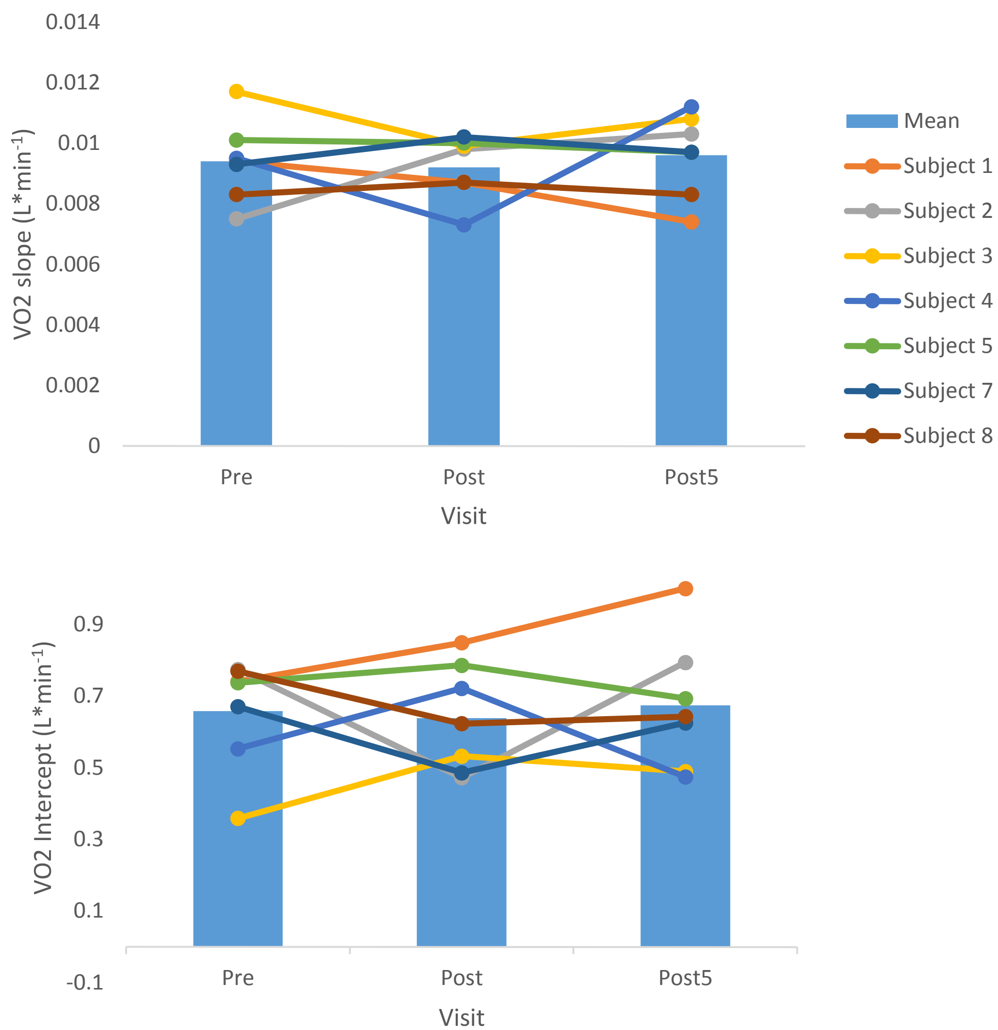

Figure 4: Subjects' (n=7) sub-maximal VO2 slope and intercept, measured from VO2 taken every 15s during workloads of 50W, 80W and 100W on a cycle ergometer. Individual values for days 1 (pre), 5 (post) and 10 (post5) is plotted via line graph, with the gr

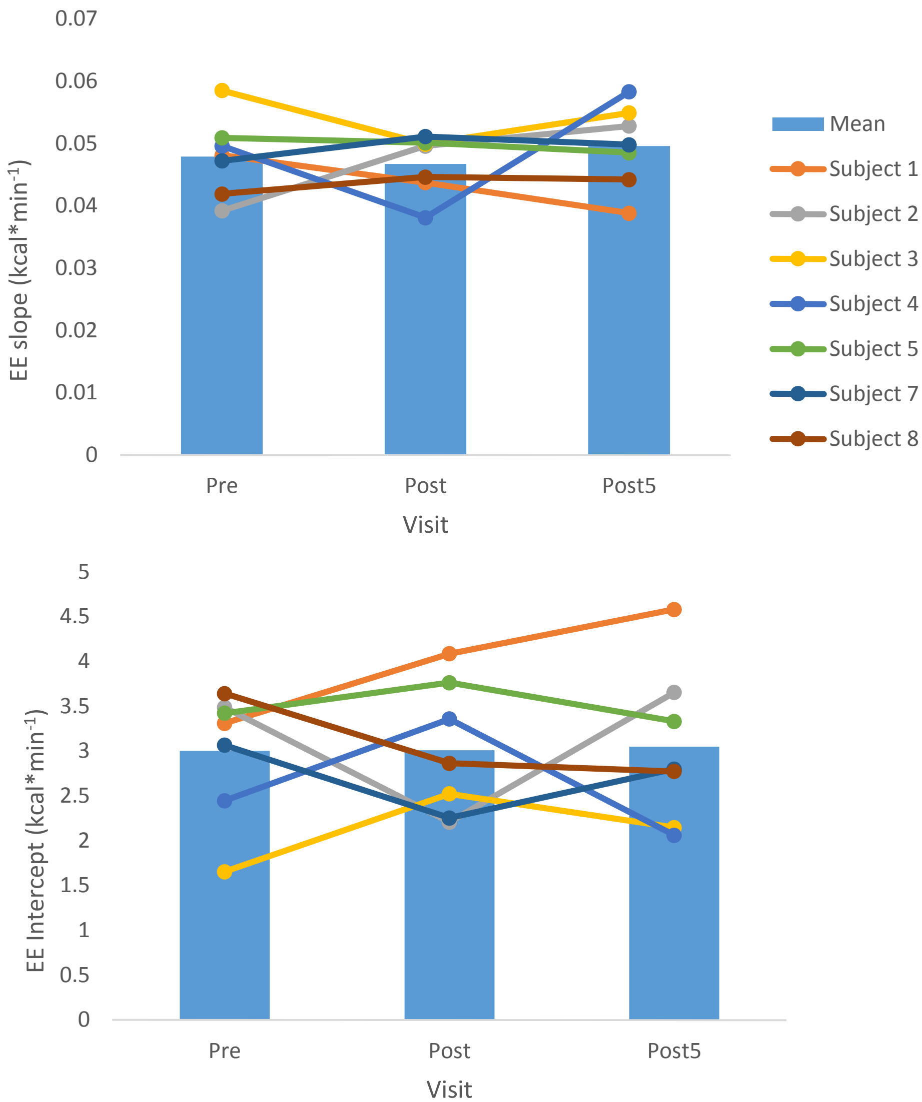

Figure 5: Subjects' (n=7) sub-maximal energy expenditure (EE) slope and intercept, measured using VO2 taken every 15s during workloads of 50W, 80W and 100W on a cycle ergometer. Individual values for days 1 (pre), 5 (post) and 10 (post5) is plotted via li

DISCUSSION

This research aimed to investigate if the microgravity environment in space impacts human energy expenditure at rest and during sub-maximal exercise, using the ground based model of HDTBR to simulate the physiological adaptations that occur during spaceflight. The results indicate that there is no statistically significant difference between either RMR or sub-maximal energy expenditure after four days of HDTBR, causing us to reject our hypothesis that we would see a decrease in the parameters of RMR and/or sub-maximal energy expenditure. This indicates that after four days of HDTBR the physiological changes of decreased muscle activation and fluid shift have little to no effect on energy expenditure at a cellular level. This leaves the question of why energy intake is so decreased unanswered. It's likely that psychological changes play the greatest role.

The low sample size of seven subjects is certainly a limitation to this experiment, as the statistical power is not as strong as it could be. However, since the p-value was so large, the low sample size likely would not affect the outcome of the study. The exclusive use of males in this study was also a drawback; including females would have been a better representation of the population and would have the potential to change our results as well. The use of males was necessity due to required experimental parameters in the larger parent study (Ryan et. al., 2016).

Since this study was looking at the short term effects of HDTBR on energetics, future studies could look into the effect of long term HDTBR. Further research should be conducted to look into energetics in astronauts and how spaceflight affects voluntary energy intake as well. Even though this study did not yield statistically significant results, it still gives us information on human energetics in a microgravity environment, and indicates that the decrease in energy intake is not due to a miscalculation in energy expenditure, but some other cause.

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