Determinants of Time to Fatigue during Non-Motorized Treadmill Exercise

John K. De Witt[1], Stuart M.C. Lee[2], Cassie A. Wilson[3], and R. Donald Hagan[4]

[1]Bergaila Engineering Services, Houston TX; [2]Wyle Life Sciences, Houston, TX; [3]JES Tech, Houston, TX; [4]NASA Johnson Space Center

Corresponding Author:
John K. De Witt, Ph.D.
Wyle Laboratories
1290 Hercules Ste 120
Houston, TX 77058-2769
Phone (281) 483-8939
fax (281) 483-4181
john.k.dewitt@nasa.gov

Address reprint requests to the corresponding author

Running Head: Factors affecting exercise to exhaustion on non-motorized treadmills

Determinants of Time to Fatigue during Non-Motorized Treadmill Exercise

ABSTRACT

Treadmill exercise is commonly used for aerobic and anaerobic conditioning. During non-motorized treadmill exercise, the subject must provide the power necessary to drive the treadmill belt. The purpose of this study was to determine what factors affected the time to fatigue on a pair of non-motorized treadmills. Twenty subjects (10 males/10 females) attempted to complete five minutes of locomotion during separate trials at 3.22, 4.83, 6.44, 8.05, 9.66, and 11.27 $km \cdot h^{-1}$. Total exercise time ($\leq$5 min) was recorded. Exercise time was converted to the amount of 15 second intervals completed. Peak oxygen uptake (VO_2) was measured using a graded exercise test on a standard treadmill, and anthropometric measures were collected from each subject before entering into the study. A Cox proportional hazards regression model was used to determine significant predictive factors in a multivariate analysis. Non-motorized treadmill speed and absolute peak VO_2 were found to be significant predictors of exercise time, but there was no effect of anthropometric characteristics. Gender was found to be a predictor of treadmill time, but this was likely due to a higher peak VO_2 in males than in females. These results were not affected by the type of treadmill tested in this study. Coaches and therapists should consider the cardiovascular fitness of an athlete or client when prescribing target speed since these factors are related to the total exercise time than can be achieved on a non-motorized treadmill.

INTRODUCTION

Treadmill exercise is a common modality for aerobic and anaerobic conditioning and rehabilitation. There are various types of treadmills available, but they generally fall into two major categories. Motorized treadmills (M) are operated with various types of motors to drive the treadmill belt. Non-motorized treadmills (NM), on the other hand, rely on the exerciser to create belt motion. NM treadmills are generally less expensive, more accessible to the average consumer, more portable, and offer locomotive exercise opportunities in locations where electrical power is unavailable.

When prescribing exercise programs, athletic coaches and exercise specialists often assign a specific treadmill speed and exercise duration as the primary training variables. However, an exercise prescription that would be appropriate on the M treadmill may not be possible on the NM treadmill because of fundamental differences in the energetic requirements between each. Consideration should be given, for example, when an athlete undergoing rehabilitation is assigned a daily regimen away from the therapist that can only be performed on a NM treadmill if the training program was designed originally for use on a M treadmill.

We recently completed a crossover-design study comparing the physiological responses and gait biomechanics on M and NM treadmills (8). A gender-balanced sample of twenty healthy subjects was tested during M and NM locomotion at various speeds. We found that at similar treadmill speeds the metabolic costs were greater on the NM treadmills. In addition, subjects were unable to exercise for as long on the NM than the M treadmill before reaching exhaustion. These data are well suited for a survival analysis because trials were completed until exhaustion (failure) or until five minutes had elapsed (survival). The Cox Proportional Hazards Model is a semi-parametric model that can be used for regression analysis of censored data (2, 3). Examination of these results may provide important insights for exercise prescription using NM treadmills.

In the study by Lee et al. (8), two different NM treadmills were used. Each treadmill had a different tread size, which may have affected locomotion. While we know that NM treadmill exercise will lead to exhaustion earlier than on M treadmills, it is not clear if factors such as stature, body size, and gender are related to survival time during NM exercise. For example, those with longer legs may be able to exercise longer because greater stride lengths may provide some biomechanical advantages when driving the treadmill belt. Similarly, those with greater body mass may have greater inherent muscle strength, thus resulting in a performance advantage when generating force to propel the treadmill belt. The purpose of this study was to determine the factors that affect the ability to exercise for up to five minutes on a NM treadmill.

METHODS

Experimental Approach to the Problem

We used a repeated measures design to test a gender-balanced sample on two NM treadmills (A/B) over six speeds. The two NM treadmills were of similar type, but were different models. Our objectives were to determine the factors that were associated with exercise time to exhaustion. A Cox proportional hazards regression model was used to determine significant predictive factors in a multivariate analysis. We hypothesized that differences in exercise duration would be explained by treadmill model, belt speed, peak VO_2, leg length, and body mass.

Subjects

Twenty subjects (10 Male/10 Female) volunteered for this study. Each subject was free from injury and had passed a United States Air Force Class III-equivalent physical examination. The methodology of this investigation was reviewed and approved by the Johnson Space Center Committee for Protection of Human Subjects. Each subject was briefed on the requirements of the study, the potential benefits, and any risks of participation. Subjects provided written informed consent prior to initiation of data collection and were free to withdraw from the study at their discretion.

Protocols

Peak VO_2 Test. Prior to the data collection sessions, each subject's peak VO_2 and maximal heart rate were measured while the subject performed a graded exercise test to volitional fatigue on a motorized treadmill (Q65, Quinton Cardiology, Inc., Bothell, WA). Heart rate and rhythm were obtained through continuous monitoring of the electrocardiogram (Q-Stress, Quinton Cardiology, Inc., Bothell, WA). The VO_2, carbon dioxide production, expired ventilation rate, and respiratory exchange ratio were measured continuously with a standard metabolic cart (TrueOne® 2400, Parvomedics, Salt Lake City, UT). Peak VO_2 was determined as the highest level of VO_2 measured during a 1-min period in which at least two of the following criteria were met: respiratory exchange ratio $\geq$ 1.10, maximal heart rate was greater than 85% of the age-predicted HR maximum, and/or a plateau of the VO_2 curve occurred. Ratings of Perceived Exertion were recorded for each stage using a 6-20 Borg Scale (1). Subjects were monitored for signs and symptoms of fatigue.

The graded exercise treadmill test consisted of a five minute warm-up of walking at 4.83 $km \cdot h^{-1}$ and three, 3-minute submaximal running stages of increasing speeds at 0% grade. The speeds for these running stages were 8.05, 9.66, and 11.27 $km \cdot h^{-1}$ for males and 6.44, 8.05, and 9.66 $km \cdot h^{-1}$ for females. Thereafter, each stage was 1 minute long during which the speed was maintained at the rate of the third submaximal stage but the grade was increased 3% per minute. This protocol has been utilized previously in ground-based studies in our laboratory (7,9,10,16). During all treadmill testing, standard exercise testing termination criteria were followed (4). Prior to performing the exercise test, each subject's height, weight and leg length from the floor to the greater trochanter of their right leg were recorded.

Treadmills. Trials were conducted on two separate treadmills. A ground-based Treadmill with Vibration Isolation and Stabilization (TVIS) currently used for locomotive exercise by astronauts onboard the International Space Station (ISS) served as Treadmill A. The TVIS was designed and constructed by NASA specifically for use on the ISS. The belt consisted of 160-1.3 cm wide aluminum slats suspended across two parallel sets of 25 roller bearings and wrapped around the front and rear drums of the treadmill. The running surface was 33 cm wide and 112 cm long. During spaceflight, the treadmill surface allows for pitch, roll, and yaw motion to dampen vibrations that could be transferred from the treadmill to the ISS. During this study, the running surface was not suspended and was fixed in an orientation parallel to the floor. No simulation of the TVIS operation in the microgravity environment was attempted. Although the treadmill can be operated in either power conditions, only data from treadmill operated in the NM mode were analyzed.

We also evaluated the non-motorized Russian-built BD-1 treadmill designed and constructed by the Institute of Biomedical Problems in Moscow, Russia (Treadmill B). The belt is made of vinyl, is 37 cm wide and 82 cm long, and passes over a series of metal rollers. Like the TVIS in the NM mode, the movement of the BD-1 belt is completely dependent upon the exerciser pushing the belt. The BD-1 treadmill was built so that the tread belt was inclined 1.79 degrees to the horizontal.

The resistance to belt motion on each treadmill can be manipulated with a braking system. For this evaluation, brakes were not engaged. We measured the belt resistance for each treadmill by determining the applied force that resulted in belt motion. Four markers were placed at equal distances from each other across the entire length of the tread belt. A weight stack with a combined weight of 61.2 kg (135 lb) was placed on the front end of the treadmill running surface with the belt positioned so that the first marker lined up with the center of the weight stack. The weight stack was attached to a load cell (Entran, Inc., Fairfield, NJ). The other end of the load cell was pulled manually in a direction parallel to the belt surface at a rate that approximated the belt speed with a subject walking on the treadmill. During the pull, the applied load was measured at 120 Hz. Load data were sampled and recorded by a data acquisition system (National Instruments, Austin, TX). The pull was terminated when the weight stack reached the aft end of the treadmill running surface. The pull test was repeated four times with each of the other three markers aligned with the center of the weight stack at the start of the pull. Each load time history was analyzed to determine the highest belt resistance during each pull. The average over the four pulls was determined for the first peak and the highest peak. We found that treadmill A had a sliding resistance of 5.16 kg. Treadmill B had a sliding resistance of 8.94 kg.

Data Collection. All subjects completed tests at six speeds ranging from 3.22 – 11.27 $km \cdot h^{-1}$. Trials were grouped in sets of three to be completed in a single day. Within a day, subjects completed either 4.83, 8.05, and 11.27 $km \cdot h^{-1}$ or 3.22, 6.44, and 9.66 $km \cdot h^{-1}$. Subjects reported to the laboratory on four separate days to complete both groups of trial speeds on both treadmills. The speed grouping and treadmill order of testing was randomized for each subject. Each subject had at least 48 hours of rest between sets of trials.

Within a set of trials, subjects attempted to complete five minutes of exercise at each treadmill speed. At least five minutes of rest was allowed between speeds. Longer rest periods were allowed based upon subject request or observational signs of fatigue. Within a testing session, the speed trials were arranged in increasing order to limit the effect of previous exercise bouts on the exercise responses. If a subject could not achieve or maintain the target treadmill speed for 30 seconds, then that within 0.178 $m \cdot s^{-1}$ for two consecutive 15-second intervals, the trial was terminated by the operators and the subject was considered to have reached fatigue. Despite verbal encouragement, most subjects terminated the trials of their own volition before the treadmill speed greatly decreased. Belt speed was recorded and reviewed for each trial to verify actual performance.

Statistical Analysis

Every subject was able to complete all five minutes at 0.89 and 1.34 m s^{-1}. Therefore, these speeds were excluded from these analyses. Student's unpaired t-tests were used to determine differences in subject characteristics between genders. We used Kaplan-Meyer curves to characterize group survival curves by treadmill and belt speed. We used Log-Rank tests to determine survival time differences between belt speeds and treadmills. Survival time was defined as the time interval until fatigue. Trials in which the entire five minutes of locomotion was completed were considered to be censored values.

We used a one-way Cox proportional hazards regression model to determine significant predictive factors in a multivariate analysis. The model was used with a forward subset selection with switching. With this procedure, the term with the largest log likelihood was entered into the model. Then all remaining terms were searched and the one that best increased the model fit, as measured with the log likelihood, was entered into the model. The procedure was repeated until either all terms had been added to the model, or no additional terms were found that increased the fit of the model. The procedure is analogous to forward stepwise multiple regression. Once the initial analysis was completed, the terms were all examined to determine those that significantly affected the model fit. The Wald test was used to test the statistical significance of individual regression coefficients. Statistical significance was defined to occur at $p<0.05$. The final model was then executed using only the significant terms.

Because the same subjects were used in each testing condition, the model was treated as a recurrent event model. The recurrent event was time of fatigue on each treadmill at each speed. Correct covariances for the estimates of each predictor parameter were computed with a robust estimator while taking into account the dependence of failure in the different conditions on the subject. All statistics were completed with NCSS 2004 software (Number Cruncher Statistical Systems, Kaysville, Utah).

RESULTS

Characteristics of the Subjects

We tested a sample consisting of males and females. Robertson et al. (14) found gender differences in absolute VO_2 between males and females. We felt that it was necessary to quantify any differences in our sample due to gender prior to further analyses. Student's t-tests indicated that females were in general shorter, lighter, had shorter legs, and possessed lower absolute peak VO_2 than their male counterparts (Table 1).

PLACE TABLE 1 ABOUT HERE

Survival Analysis

Kaplan-Meyer survival curves for each treadmill at 6.44, 8.05, 9.66, and 11.27 $km \cdot h^{-1}$are shown in Figure 1. Each plot is pooled across the entire sample. Survival plots were similar between treadmills at each speed, but as speed increased, the rate of failure increased.

PLACE FIGURE 1 ABOUT HERE

The Log-Rank tests revealed that the survival times for the group decreased as speed increased ($p<0.05$). It should be noted that at 9.66 and 11.27 $km \cdot h^{-1}$, the mean survival times were underestimated due to the large number of censored variables (Table 2). There were no significant differences in survival times between treadmills.

PLACE TABLE 2 ABOUT HERE

Cox Regression

An initial analysis was conducted to determine the appropriate tie-handling procedure. There were many ties at the shorter time intervals. Since the purpose of the study was to explore the effects of covariates upon locomotion time to failure, it was decided to use the Efron (3) method to handle ties.

Initial Analysis. Since the analysis was exploratory, all variables were added to the model and a regression analysis was used to determine significant predictors of survival. Belt speed, gender, and treadmill were considered as categorical independent variables. Body mass, absolute peak VO_2, and leg length were considered as numeric independent variables. Relative peak VO_2 was not included in the analysis because it is a function of mass and absolute peak VO_2. If both mass and absolute peak VO_2 were found to be significant predictors, then a secondary analysis would be undertaken to establish if eliminating these two variables and adding relative peak VO_2 affects the fit of the model.

The regression analysis revealed that survival was significantly related to belt speed, peak absolute VO_2, and gender. Treadmill model approached significance ($p=0.067$); leg length and body mass were not significant predictors. The parameter estimates, hazard ratios, and 95% confidence intervals are shown in Table 3.

PLACE TABLE 3 ABOUT HERE

Secondary Analysis. The Cox regression was then executed using only the significant terms found during the initial analysis. All parameter estimates and hazard ratios are shown in Table 4. The final model had a log likelihood of –431.43 and an r-squared of 0.83.

PLACE TABLE 4 ABOUT HERE

Test of Proportionality Assumption

Because the Cox proportional hazard model assumes that the ratio of hazard between subjects with different characteristics is constant over time, it is important that the proportional hazard assumption is met. In this data set, the dichotomous variable that was found to affect survival time that separated subjects was gender. The hazard functions of the male and female subjects were parallel, suggesting that the proportionality assumption holds (Figure 2).

PLACE FIGURE 2 ABOUT HERE

DISCUSSION

The results of our study suggest that the time to exhaustion during treadmill exercise is significantly affected by running speed and the subject's cardiovascular fitness expressed as peak absolute VO_2. In our sample, gender also was related to time to fatigue, with males able to exercise longer than females at a given speed. However, the apparent influence of gender is clouded by the significant difference in, peak absolute VO_2, observed between the male and female subjects. In addition, our males were heavier and taller than their female counterparts. When body mass was taken into account, there were no differences in relative peak VO_2 between genders. These findings suggest that absolute cardiovascular fitness, rather than relative peak VO_2, differentiate our subjects and significantly affect time to fatigue on a NM treadmill.

We also found that treadmill type (A vs. B) did not influence time to fatigue. However, there was a trend towards a treadmill effect ($p=0.067$). It is possible that the differing characteristics between the treadmills, such as belt resistance and belt inclination, could affect exercise performance. Practitioners should write prescriptions based upon the characteristics of the particular treadmill that will be used. Treadmill features can affect the tolerance to exercise. Furthermore, the anthropometric measures did not predict time to fatigue, indicating that body mass and leg length do not help nor hinder exercise times.

The advantage of the Cox regression model is that it allows for the calculation of odds ratios between categories of specific factors while controlling for all other factors. Our fitted model indicates that, while controlling for all other factors, when compared to locomotion at 11.27 $km \cdot h^{-1}$, subjects were 333.33, 40.00, and 4.73 times more likely to be able to complete 5 minutes of exercise at 6.44, 8.05 and 9.66 $km \cdot h^{-1}$, respectively. In addition, subjects were 8.33 times more likely to complete 6.44 than 8.05 $km \cdot h^{-1}$, 70.33 times more likely to complete 6.44 than 9.66 $km \cdot h^{-1}$, and 8.44 times more likely to complete 8.05 than 9.66 $km \cdot h^{-1}$. Females were 2.08 times more likely to fail than males, and for a 1 $l \cdot min^{-1}$ increase in peak absolute VO_2, the hazard ratio for failure decreased by a factor of 1.73 regardless of gender.

Although gender was found to affect time to fatigue, we suspect that this may be due to differences in the demographics of our sample, and not necessarily due to gender itself. During a post hoc evaluation, we looked at the data from one of our female subjects, who had an absolute peak VO_2 of 3.15 $l \cdot min^{-1}$. The absolute peak VO_2 score is similar to that of the mean of our male sample. Examination of her data suggests that she was able to perform longer than the rest of the females and her scores were similar to the males with similar fitness levels. We re-executed the Cox regression analysis excluding this subject and found that the log likelihood of the model to increase to –393.58 and the r-squared to increase to 0.86. In addition, the hazard ratio for females rose to 3.40. These findings suggest that the gender effect that we identified may be amplified due to the absolute fitness levels between genders.

The effect of speed and peak absolute VO_2 on time to exhaustion is not surprising. As a person runs faster, they will tire quicker (6). Our data indicate that increments of 1.61 $km \cdot h^{-1}$ are enough to see significant differences in time to fatigue. Each increment appears to reduce the chance for success (completing 5 minutes) by a factor of ten. Peak absolute VO_2 is a measure of aerobic fitness. Generally, the more aerobically fit a person is, the longer they can tolerate and meet the metabolic demands of exercise before exhaustion (13). The anaerobic threshold is defined as the level of VO_2 consumption just below that at which metabolic acidosis occurs (15). It is probable that the more fit subjects were exercising at a lower percentage of their maximal capability and were less likely to be performing at or above their anaerobic threshold.

There have been no studies yet that have shown effectiveness of NM treadmill training as a training modality. Our results quantify factors that are related to NM treadmill exercise performance as it relates to fatigue. Ott et al. (11) reported that walking at 3.20 $km \cdot h^{-1}$ and 4.82 $km \cdot h^{-1}$ at 10% grade on non-motorized treadmills resulted in 35% greater VO_2 and 18% greater heart rate than motorized treadmill exercise. Lee et al. (8) found that at similar speeds, $VO_2$was greater on an M than NM treadmill at identical speeds. In their study, test subjects commented that it was more difficult to perform on the NM treadmills, and that NM treadmill locomotion felt similar to running up an incline. Margaria et al. (11) found that the energetic cost for running increased with incline. It is possible that NM treadmill locomotion is more similar to inclined M exercise. Future study is necessary to compare NM locomotion to M locomotion on an inclined treadmill to determine if there exists an incline that results in similar M-NM performance.

PRACTICAL APPLICATIONS

NM treadmills can be used in a fitness program for treadmill exercise. These types of treadmills may be attractive because they may be less expensive than their M counterparts, are more portable, and may be used in facilities and environments where electrical power is unavailable. Longer exercise bouts on a NM treadmill at the same absolute treadmill speed are more difficult to complete, are conducted at a higher percentage of an individual's aerobic exercise capacity, and potentially requires a significant anaerobic component when compared to M treadmills (8). None of our subjects could complete five minutes of steady state exercise on the NM treadmills at speeds equal to or greater than 9.66 $km \cdot h^{-1}$, and some subjects were not able to complete the five minutes at 8.05 $km \cdot h^{-1}$. The increased fatigue was probably due to the increased energy required not only to lift the body, as in motorized treadmill running, but also to propel the belt.

Our findings suggest that when prescribing exercise on a NM treadmill, coaches and therapists should be aware of the increased metabolic cost at a given speed and not be surprised when athletes cannot exercise for long periods of time, even at what are perceived to be slow to moderate belt speeds. Subjects exercise at a greater VO_2 on the NM treadmill, resulting in an earlier time to fatigue on a NM than M treadmill at a given speed. NM treadmill training may be an efficient interval training modality given the increased energy requirements as compared to M treadmills and may be well suited for interval exercise training, which has been shown to be an effective means to increase cardiovascular fitness (4). In addition, because NM treadmill exercise requires greater effort at a given velocity when compared to M treadmill exercise, coaches may consider using RPE and/or HR when determining prescriptions rather than treadmill speed.

REFERENCES

1. Borg G. Perceived Exertion as an indicator of somatic stress. *Scand J Rehab Med.* 2:92-98. 1970.

2. Cox D.R. Regression models and life tables. *J. Royal Statistical Society. Series B (Methodological).* 34:187-220. 1972.

3. Efron B. The efficiency of Cox's likelihood function for censored data. *J. American Statistical Association.* 72:557-565. 1977.

4. Gorostiaga E.M., C.B. Walter, C. Foster and R.C. Hickson. Uniqueness of interval and continuous training at the same maintained exercise intensity. *European J Appl Physiol*. 63:101-107. 1991.

5. Holly, R.G. and K.E. Clinical exercise testing procedures. In: *Clinical exercise prescription: theory and application*. eds. Roberts, S.O., R.A.

Robergs, R. A., and P.G. Hanson, eds. Boca Raton, FL:CRC Press, 1997. pp. 125-153.

6. Hill, D.W., and C.S. Ferguson. A physiological description of critical velocity. *European J Appl Physiol*. 79:290-293. 1999.

7. Lee S.M.C., B.S. Bennett, A.R. Hargens, D.E. Watenpaugh, R.E. Ballard, G. Murthy, S.R. Ford, and S.M. Fortney. Upright exercise or supine lower body negative pressure exercise maintains exercise responses after bed rest. *Med Sci Sports Exerc*. 29:892-900. 1997.

8. Lee, S.M.C., J.K. De Witt, C. Smith, M.S. Laughlin, J.A. Loehr, J. Norcross, and R.D. Hagan. Physiologic responses and biomechanical aspects of motorized and non-motorized treadmill exercise: A ground-based evaluation of treadmills for use on the International Space Station. *National Aeronautics and Space Administration Technical Report 20060052414*. 2006.

9. Lee, S.M.C., M.E. Guilliams, and S.M. Schneider. Exercise countermeasures during the Lunar-Mars life support test project phases IIa and III. In: *Isolation: NASA experiments in closed-environment living: advanced human life support enclosed system final report*. Lane, H.W., R.L. Sauer, and D.L. Feedback, eds. San Diego: Univelt, Inc., 2002. pp. 315-342.

10. Lee S.M.C., S.M. Schneider, D.E. Watenpaugh, A. Lanemack, W.L. Boda and A.R. Hargens. Supine LBNP exercise maintains upright exercise capacity after 30-d bed rest. *Med Sci Sports Exerc*. 33:S2982001. 2001.

11. Margaria, R., P. Cerretelli, P. Aghemo and G. Sassi. Energy cost of running. *J Appl Physiol*. 18: 367-370. 1963

12. Ott, R.M., J. Wygand, K. Flanagan, E. Rowley, M. McPhilliamy, and B. Stewart. A comparison of metabolic responses to walking on motorized and non-motorized treadmills. *Med Sci Sports Exerc*. 29:203. 1997.

13. Phillips, S.M., H.J. Green, M.J. MacDonald and R.L. Hughson. Progressive effect of endurance training on VO2 kinetics at the onset of submaximal exercise. *J Appl Physiol.* 79:1914-1920. 1995.

14. Robertson R.J., N.M. Moyna, K.L. Sward, N.B. Millich, F.L. Goss, and P.D. Thompson. Gender comparison of RPE at absolute and relative physiological criteria. *Med Sci Sports Exerc.* 12:2120-2129. 2000.

15. Wasserman K., B.J. Whipp, S.K. Koyal, and W.L. Beaver. Anaerobic threshold and respiratory gas exchange during exercise. *J Appl Physiol.* 35:236-243. 1973.

16. Watenpaugh D.E., R.E. Ballard, S.M. Schneider, S.M.C. Lee, A.C. Ertl, J.M. William, W.L. Boda, K.J. Hutchinson, and A.R. Hargens. Supine lower body negative pressure exercise during bed rest maintains upright exercise capacity. *J Appl Physiol.* 89:218-227. 2000.

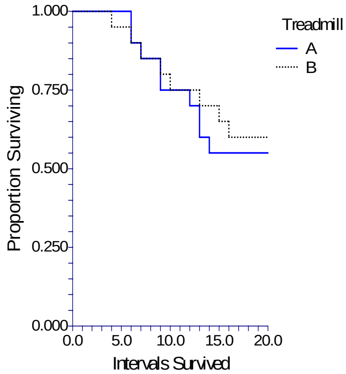
ACKNOWLEDGMENTS

We wish to thank the Exercise Countermeasures Project at NASA Johnson Space Center for their budgetary and programmatic support and Yong-Fang Kuo, Ph.D. at the University of Texas Medical Branch for her assistance with the statistical analysis in this paper. We would also like to thank members of the Exercise Physiology Laboratory for their aid in data collection and the test subjects for their participation.

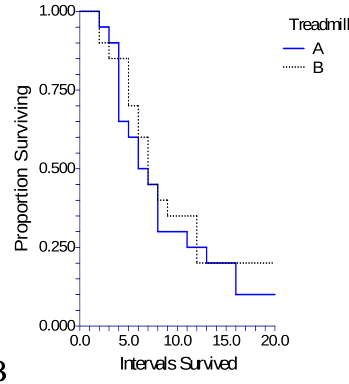
FIGURE LEGENDS

Figure 1. Estimated survival among subjects on the NM treadmills at 6.44 (panel A), 8.05 (panel B), 9.66 (panel C), and 11.27 $km \cdot h^{-1}$ (panel D). Each interval represents 15 seconds.

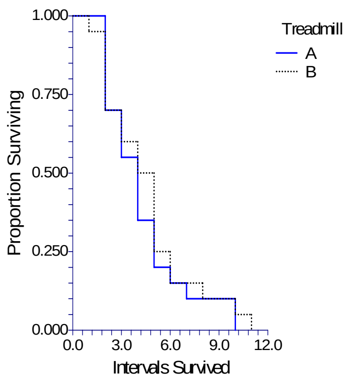
Figure 2. Hazard functions among male and female subjects for all speeds. Each interval represents 15 seconds.


Proportion Surviving
1.000
0.750
0.500
0.250
0.000
0.0
5.0
10.0
15.0
20.0
Intervals Survived
Treadmill
A
B

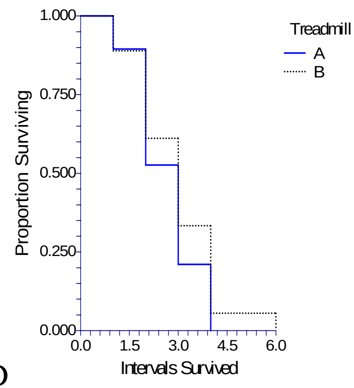
A


Proportion Surviving
1.000
0.750
0.500
0.250
0.000
0.0
5.0
10.0
15.0
20.0
Intervals Survived
Treadmill
A
B

B


Proportion Surviving
1.000
0.750
0.500
0.250
0.000
0.0
3.0
6.0
9.0
12.0
Intervals Survived
Treadmill
A
B

C


Proportion Surviving
1.000
0.750
0.500
0.250
0.000
0.0
1.5
3.0
4.5
6.0
Intervals Survived
Treadmill
A
B

D

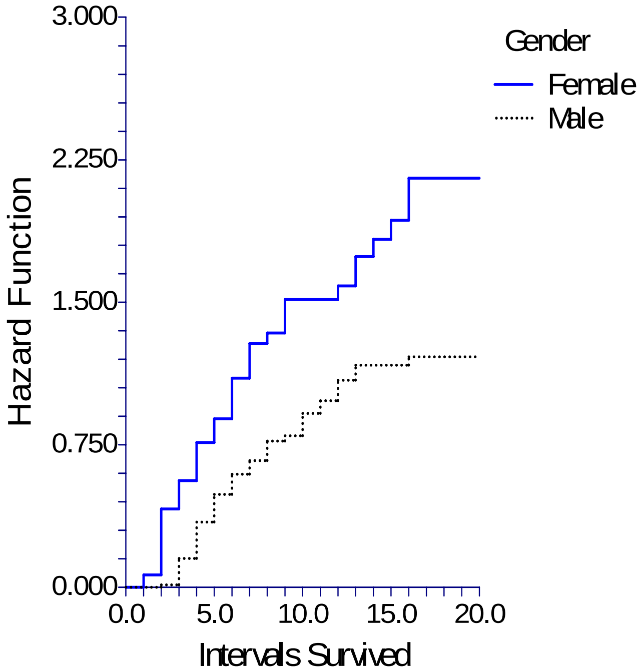

Gender
Female
Male
Hazard Function
3.000
2.250
1.500
0.750
0.000
0.0
5.0
10.0
15.0
20.0
Intervals Survived

Table 1. Characteristics of subjects participating in the study (mean ± SD)

	Male	Female
Age (yrs)	33±6	29±4
Height (cm)	179.5±6.0	164.0±5.0*
Body Mass (kg)	77.8±7.2	57.3±8.3*
Leg Length (cm)	85.8±5.7	81.7±5.7*
Peak VO_2 ($l \cdot min^{-1}$)	3.59±0.62	2.64±0.50*
Relative VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$)	45.8±6.6	45.9±4.9
Maximal Heart Rate ($beats \cdot min^{-1}$)	191±9	189±10

*$p<0.05$

Table 2. Survival data grouped by speed and treadmill. Completed trials were those where the subject finished the five-minute run (Mean ± SD).

Speed ($km \cdot h^{-1}$)	Treadmill	Trials Completed	Trials Failed	Mean Survival Time (intervals)
6.44	A	11	9	12.15 ± 0.68
	B	12	8	13.6 ± 0.93
8.05	A	2	18	8.05 ± 1.09
	B	4	16	7.80 ± 0.81
9.66	A	0	20	4.25 ± 0.55
	B	0	20	4.55 ± 0.60
11.27	A	0	20	2.50 ± 0.25
	B	0	20	2.65 ± 0.03

Table 3. Cox regression coefficients, Wald Z-values, hazard ratio, and 95% confidence limits for all terms predicting time to failure during NM treadmill running.

Term		Parameter Estimate	Wald Z-Value	Pr > ChiSq	Hazard Ratio	95% Hazard Ratio Confidence Limits
Speed	6.44 $km \cdot h^{-1}$	-6.23	-12.88	0.000	0.002	0.001-0.005
Speed	8.05 $km \cdot h^{-1}$	-3.79	-10.40	0.000	0.022	0.011-0.046
Speed	9.66 $km \cdot h^{-1}$	-1.58	-5.94	0.000	0.205	0.121-0.346
Peak Absolute VO_2		-1.60	-6.10	0.000	0.202	0.121-0.338
Gender	F	1.20	3.00	0.003	3.309	1.513-7.235
Treadmill	B	-0.33	-1.83	0.067	0.718	0.504-1.023
Leg Length		-0.05	-1.68	0.092	0.951	0.896-1.008
Mass		0.03	1.18	0.240	1.025	0.983-1.069

Table 4. Parameter, hazard ratios, and 95% confidence limits for significant factors predicting time to failure during NM treadmill running.

Parameter		Parameter Estimate	Wald Z-Value	Pr > ChiSq	Hazard Ratio	95% Hazard Ratio Confidence Limits
Speed	6.44 $km \cdot h^{-1}$	-6.01	-12.96	<0.001	0.003	0.001-0.06
Speed	8.05 $km \cdot h^{-1}$	-3.68	-10.31	<0.001	0.025	0.013-0.051
Speed	9.66 $km \cdot h^{-1}$	-1.56	-5.90	<0.001	0.211	0.126-0.354
Peak Absolute VO_2		-1.73	-8.45	<0.001	0.177	0.119-0.265
Gender	F	0.73	3.44	0.001	2.075	1.369-3.146