Teal Cycle Ergometer Vibration Isolation and Stabilization System Human-in-the-Loop Ground Evaluation for Long-Duration Spaceflight

Dillon J. C. Frisco[1], Jennifer L. Sullivan[2], Brian J. Prejean[2], Alyssa N. Varanoske[2], Nicole C. Strock[2], Danielle Conly[2], Brett A. Siders[3], Lori L. Cooper[1], Karina J. Marshall-Goebel[4], Renita S. Fincke[4]

[1]JES Technologies, [2]KBR, [3]Aegis Aerospace, [4]NASA Johnson Space Center

Abstract

Purpose: To counter the deleterious effects of weightlessness on the cardiopulmonary system, astronauts living on the International Space Station exercise on a variety of countermeasure equipment including the Cycle Ergometer Vibration Isolation and Stabilization System (CEVIS). Operational since 2001, the onboard CEVIS will be replaced by a new model, known as Teal CEVIS (TC). As a part of ground evaluation, TC hardware underwent human-in-the-loop (HITL) testing to verify the TC hardware produces workloads that elicit physiologic responses comparable to a laboratory cycle ergometer (LAB). **Methods**: Seven subjects (5 M/2 F) performed submaximal cycle ergometer testing with indirect calorimetry measures on TC and LAB on separate test days. Testing consisted of graded 30 watt increases in workload until subjects reached 85% of age-predicted max heart rate (HR). Exercise outcomes included rate of oxygen uptake (VO2; liters/min), rate of energy expenditure (REE; kcal/min), and HR (beats/min). Linear mixed models (LMM) were fitted to compare VO2, REE, and HR responses between devices across power outputs with fixed effects for power (P) and device (D) and with random effects for subject. LMM effect coefficients (β), std errors (SE), pseudo-partial R2 of effects (pR2), and model likelihood ratio statistics ($\chi 2$, Pr(> chisq); α<.05) are provided. **Results**: LMM main effects for P and D were observed for VO2 (βp=.0107, SE = .0002, pR2=0.97; βd = -0.075, SE = 0.019, pR2=0.14; $\chi 2(1)$= 13.57, p<.001), such that VO2 was higher across stages on TC. Main effects of P and D were observed for REE (βp= .0586, SE = 0.001, pR2= 0.97; βd = -0.33208, SE = 0.099, pR2= 0.056; $\chi 2(1)$=10.481, p < .01), such that REE was higher across power outputs on TC. A P x D interaction was observed for HR, along with main effects for P and D (βp x d =-0.048, SE = 0.02, pR2=0.048; βp= 0.42, SE = 0.016, pR2=0.87; $\chi 2(1)$ = 5.398, p = 0.02), such that higher workloads elicited a greater difference in HR between devices. **Conclusions**: HITL results show, TC elicits greater physiologic responses across power outputs compared to LAB. However, pR2 for device effects show small differences between devices. Therefore, TC can be expected to provide appropriate physiological stimulus across workloads and be considered a reliable tool to mitigate the effects of weightlessness.

Introduction & Purpose

- Astronauts living aboard the International Space Station (ISS) are required to engage in a variety of exercise routines to mitigate the negative effects of weightlessness on the cardiopulmonary system
- The onboard Cycle Ergometer and Vibration Isolation and Stabilization system (CEVIS) is one of the primary aerobic exercise capabilities on the ISS
- Recently, a new “Teal” CEVIS (TC) was developed for in-flight operations and required ground evaluation before flight
- As a part of extensive pre-flight evaluation, the TC underwent human-in-the-loop testing to verify the TC provides physiological responses during exercise comparable to a research grade cycle ergometer (LAB)
- **Purpose: Compare metabolic and physiologic responses between the TC and LAB**

Methods

- Healthy subjects (Table 1) were recruited from the Johnson Space Center workforce
- Subjects completed graded exercise test (GXT) sessions on a TC and the LAB on subsequent days (randomized order)
- The GXT protocol began with subjects cycling at 90 watts and increased by 30 watts every 3 min until participants reached 85% of age predicted max heart rate (Figure 1)
- Rate of Oxygen consumption (VO2) and Rate of Energy Expenditure (REE) were analyzed via indirect calorimetry using a Parvo Medics' TrueOne® 2400; Heart rate was measured via Polar H10
- VO2, REE, and heart rate averaged over the last minute of each power stage were used for analysis

Table 1. Subject characteristics. n = subject numbers. Variables are represented as Mean and range.

	n	Age (years)	Height (inches)	Weight (pounds)
Female Subjects	2	29.5 (27,32)	71.5 (70,73)	158.5 (150,167)
Male Subjects	5	35 (23,41)	73.2 (71,75)	195.8 (158,224)

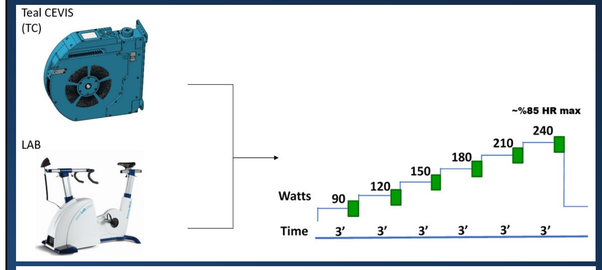

Figure 1. Study Design. Subjects performed GXT’s on both the TC (top left) and the LAB (bottom left) on back to back test days. An example GXT (right) profile illustrates the increasing incremental power outputs with green boxes indicating 1 min sampling periods. The GXT continued increasing in power until ~ 85% of HR max.

- Linear mixed models were fitted to evaluate fixed effects of power and device conditions on physiologic responses while accounting for random effect of subject
- Model selection was conducted using likelihood ratio testing; Model outputs are represented in Figures 2-4

Results

VO2 Analysis

- Mixed modeling indicated that VO2 was higher across power outputs in the TC condition compared to the LAB condition (Figure 2)

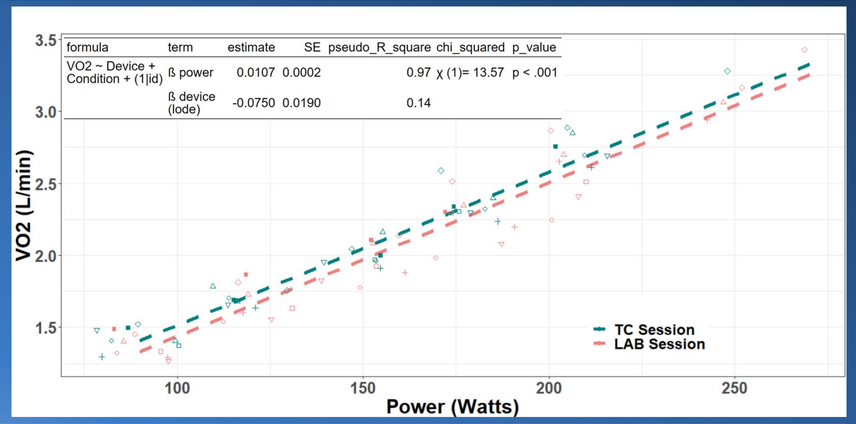

Figure 2. VO2 was found to be higher across power outputs in the TC device condition compared to the LAB ergometer condition. This plot represents linear mixed model fitted estimates of TC (teal dashed line) and LAB (coral dashed line). Shapes represent subject VO2 values over the protocol power outputs. The table represents LMM diagnostic and selection criterion.

Results

REE Analysis

- Mixed modeling indicated that REE was higher across power outputs in the TC condition compared to the LAB condition (Figure 3)

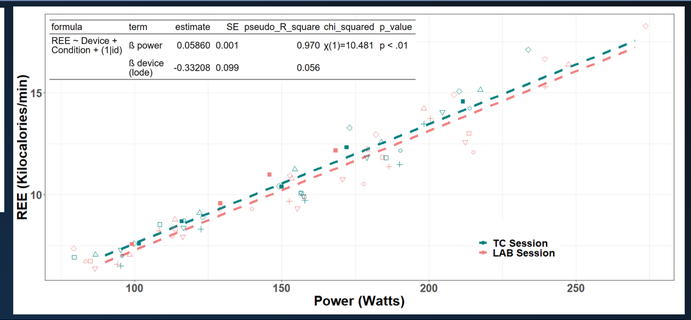

Figure 3. REE was found to be higher across power outputs in the TC device condition compared to the LAB ergometer condition. This plot represents linear mixed model fitted estimates of TC (teal dashed line) and LAB (coral dashed line). Shapes represent subject REE values over the protocol power outputs. The table represents LMM parameters and selection criterion.

HR Analysis

- Mixed modeling revealed an interaction between device and power such that the subject heart rates on TC were increasingly greater than LAB at higher power outputs. (Figure 4)

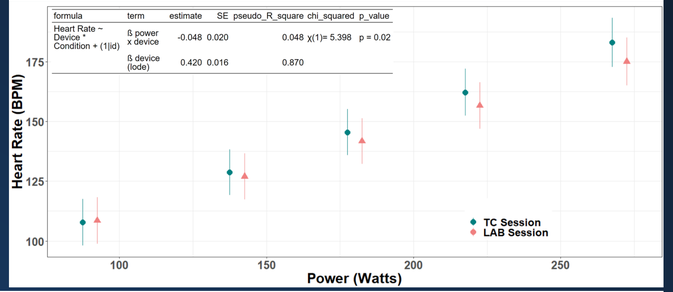

Figure 4. For HR mixed modeling, a Device x Power interaction effect was found. Indicating a difference in HR between device conditions depending on power output. The plot shows the HR model’s estimated marginal means with 95% confidence intervals error bars. Teal represents TC model estimates and Coral represents LAB. The table shows linear mixed model parameters and selection criterion.

Discussion & Conclusions

- Astronauts rely on exercise countermeasure hardware to provide consistent and appropriate physiologic stimulus to counter the effects of weightlessness, thus, it was critical to evaluate the ability of TC to provide this stimuli.
- Data show consistently elevated metabolic responses across power outputs on TC as compared to LAB. This may be due do the variability in the ergometer power output mechanism.
- Additionally, heart rates were elevated at increasing workloads in the TC condition with the interaction being most pronounced at 210 and 270 W. One possible explanation for the dissociation of heart rate and VO2 at higher power outputs may have been solely due to differences in environment (e.g. heat which potentiated heart rate differences between devices).
- However, given that the effect of device is minimal, the TC exercise ergometer can be reasonably expected to provide sufficient physiologic responses during exercise.

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