Multivariate Analysis of Human Health and Performance in an Acute Spaceflight Simulation

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Aims

1) Identify and classify stress using physiological signals
2) Search for a relationship between sensorimotor performance and physiological health
3) Describe the physiological characteristics of adaptation

Introduction

- Optimal human performance requires proper orchestration of different physiological and psychological systems.
- In the context of extended spaceflight, the ability to perform is crucial to the success of the mission.
- While the health effects of spaceflight are normally studied individually and separately, evidence points to the value of an **integrated approach**[1,2] for looking across different health domains, since performance outcomes are determined by the integration of multiple body systems.
- We propose to use **multivariate analysis techniques** to examine various health and performance measures.
- To test this, we devised an experiment that simulated the **sensorimotor stresses** of spaceflight and collected continuous physiological and performance data from it using various devices.

Fig. 1: Various sensorimotor perturbations and activities done during the experiment that aim to mimic spaceflight.

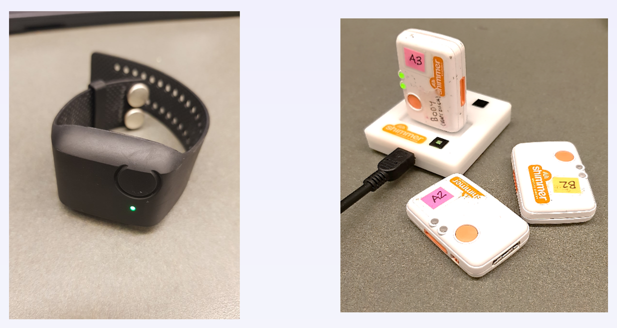

Fig. 2: The Empatica E4 wristband used to take physiological measures (left), and the Shimmer3 IMU used to measure body acceleration (right).

- 45 healthy subjects performed the experiment. Informed consent was obtained in accordance with IRB regulations.

Experiment Design

- The experiment consists of 3 phases: **unperturbed phase** (seated), **perturbed phase** (standing), and **recovery phase** (seated). Each phase consists of two rounds, with 25 min of copying an article and a 5 min break.
- Perturbations: **prism glasses** to induce vertical skew and **weighted body vest** tuned to 10% of the subject's weight.
- For the duration of the experiment, the following measurements were taken:
  - Heart Rate (HR)
  - Skin Conductance (EDA)
  - Skin Temperature (TEMP)
  - Inter-beat Interval (IBI)
  - Body Motion (arms, torso, head) (ACC)
  - Vertical Ocular Alignment (VAN)
  - Perceived stress level (Likert Scale)
  - Task Completion Time
  - Average typing speed, words per minute, keystroke intervals

Analysis

1. We had two steps to analyze our signals:
   a. **Feature extraction** from signals (Fig. 3-6)
   b. **Stress detection** using classification algorithms like logistic regression and support vector machines

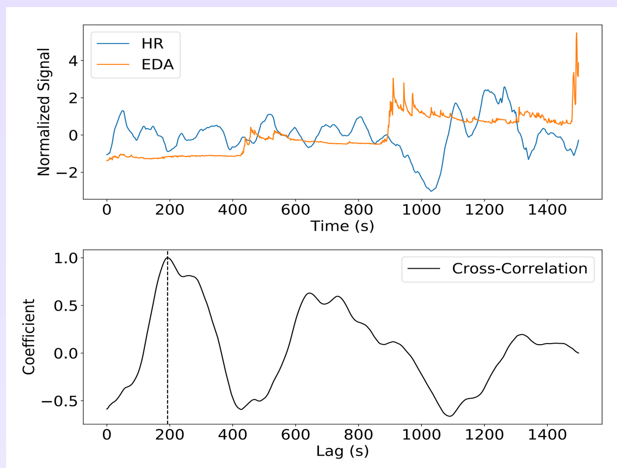

Fig. 3: Demonstration of cross-correlation lag time for HR and EDA signals. Here, the heart rate lags the EDA by 200 seconds.

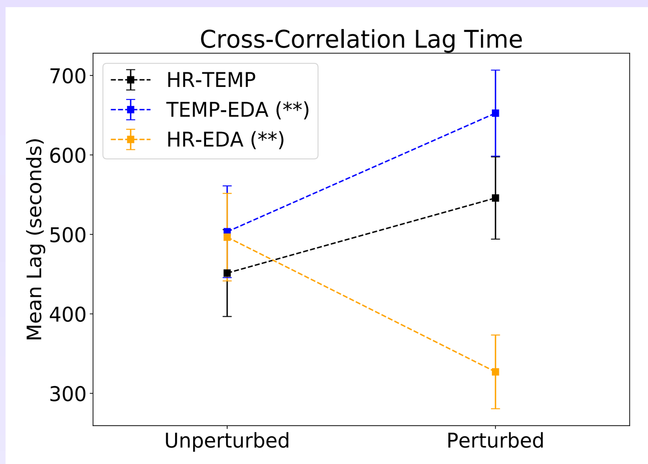

Fig. 4: Mean lag time for pairwise combinations of signals. ** indicates a Mann-Whitney difference with $p < 0.05$.

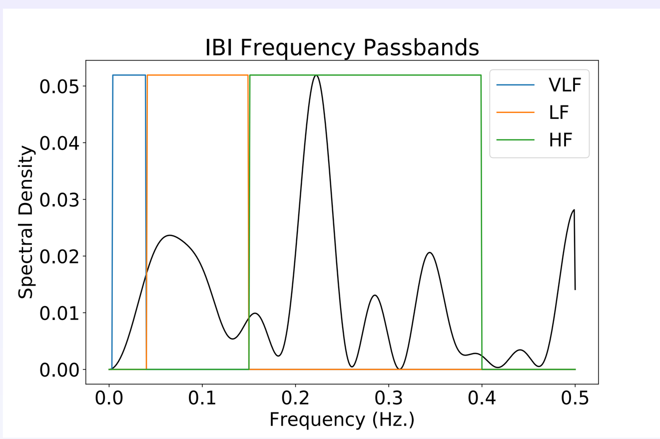

Fig. 5: We integrate over low, high, and very high frequency passbands and compute frequency-domain statistics for the inter-beat interval signal.

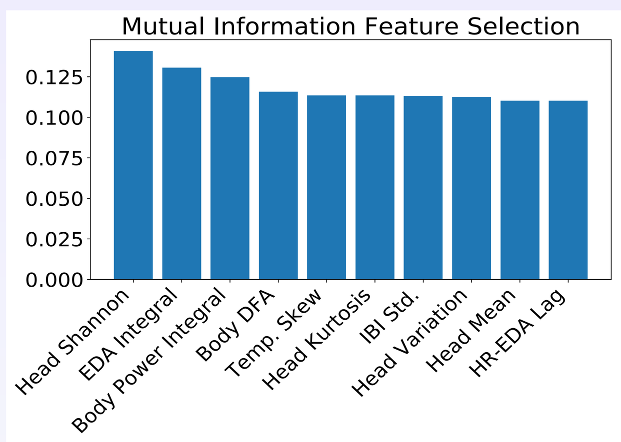

Fig. 6: Selection of best features via mutual information score. These ten features encode the most information about perturbation and stress level.

Results

1. Stress detection (binary classification) with a sensitivity-specificity AUC score of **0.94**, and an accuracy of **85%** on our data (cross-validated)
2. The multivariate approach is superior to isolated methods, with a higher accuracy

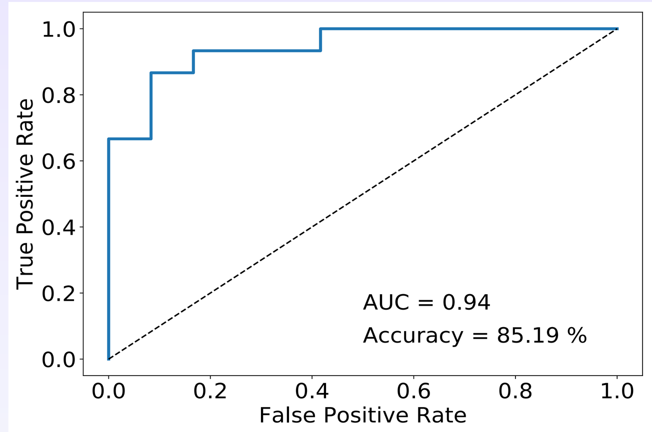

Fig. 7: Receiver-operating characteristic (ROC) curve for our logistic regression classifier.

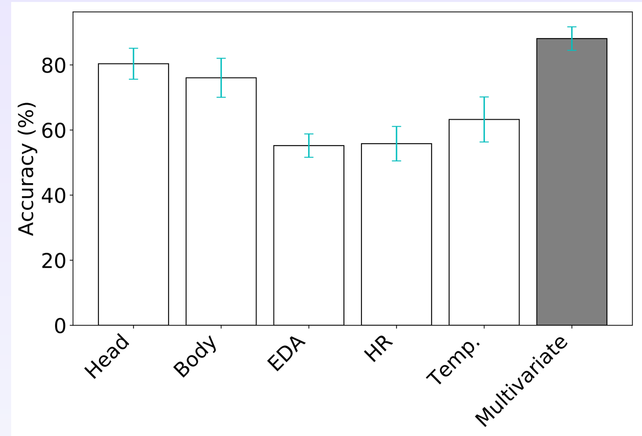

Fig. 8: Comparison of classification accuracy using different isolated signals versus their combined information.

Preliminary Conclusions & Future Work

- We have developed a tool that enables us to predict the perceived stress level of a subject solely from signals collected via a wristband sensor.
- We have shown that multivariate analysis markedly improves classification accuracy.
- We have identified and written over a dozen signal statistics that are powerful at detecting perturbations.
- Currently, we are working on:
  1. Packaging our code into a software tool for all researchers
  2. Studying physiological adaptation to sensorimotor perturbations.
  3. Using known physiological stress responses to predict performance in sensorimotor tasks.

Challenges

1. Which measures accurately identify signals physiologically coupling and decoupling?
2. How can we best analyze and use our performance data (such as keystroke metrics, performance times, etc.)?
3. What other hypotheses can be tested with multivariate physiological data in the context of spaceflight?

References

[1] Chiel, H. J. & Beer, R. D. (1997) Trends in Neurosciences 20, 553–557.
[2] Li, X. et al (2017). PLOS Biology, 15(1).

Vestibular and Postural Assessment Device and Methods

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Aims

1) Augment an existing binocular alignment test called VANTAN by adding a postural sway assessment
2) Test the device and use it to search for a relationship between postural sway and binocular misalignment
3) Examine the effects of postural demand on vestibular function

Introduction

- Changes in otolith function as a result of prolonged exposure to weightlessness may result in a **decrease in overall sensorimotor capability**.
- NASA currently addresses this risk through several **post-flight sensorimotor assessments**, which can guide future preventive measures.
- We propose an alternative simple, fast and cost-efficient way to carry out this monitoring using an **augmented binocular alignment test** called VANTAN (Vertical/Torsional Alignment Nulling test) that has a posture analysis test added to it.
- This device could allow us to:
  - **Reduce the need for more involved posture testing** after spaceflight
  - **Gain a better understanding of the relationship between postural control and ocular alignment**, both of which are functional manifestations of the otolith organs
  - **Assess and predict postural and ocular alignment** changes post-flight
  - **Assess postural and ocular alignment changes during spaceflight**, such as when astronauts are held by elastic cords to a treadmill. This would be a completely new capability.

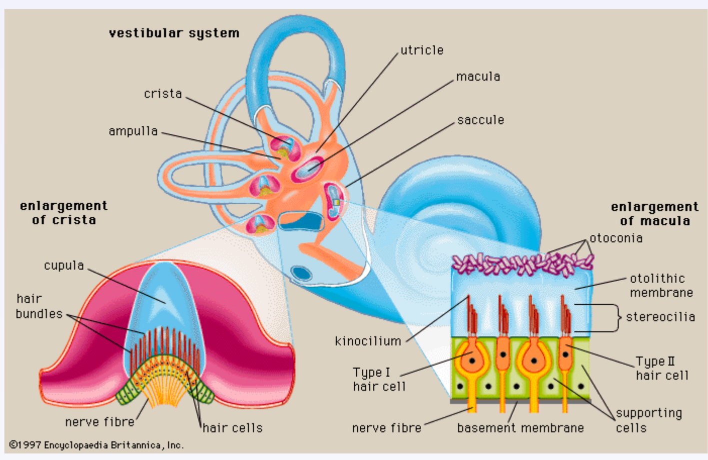

Fig. 1: The vestibular system in detail.

Fig. 2: An astronaut running on the treadmill on the International Space Station.

Experiment Design

The aims of the experiment are to:

- Search for a **relationship between postural sway and eye misalignment** by observing changes in both systems as a result of a vestibular perturbation.
- Determine if **engaging posture may have an upstream effect** on the vestibular system.

Subjects were taken through the following conditions, in order, during the experiment:

1. VANTAN measurements:
   - Seated, with and without perturbation
   - Standing on foam beam, with and without perturbation
2. Postural sway measurement (20 sec.):
   - Seated, eyes closed, feet together, with and without perturbation
   - Standing on foam beam, eyes closed, feet together, with and without perturbation

A 92 Hz vibration device was used as the vestibular perturbation. A Surface tablet was used to take all measurements. Five subjects were interviewed for balance and vision difficulties before being tested. Informed consent was obtained in accordance with IRB regulations.

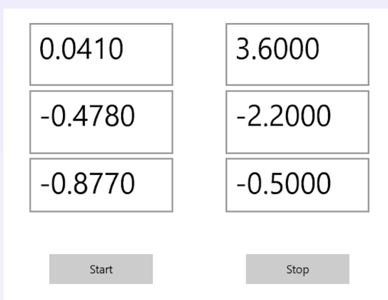

Fig. 3: Example of accelerometer measurement for postural sway.

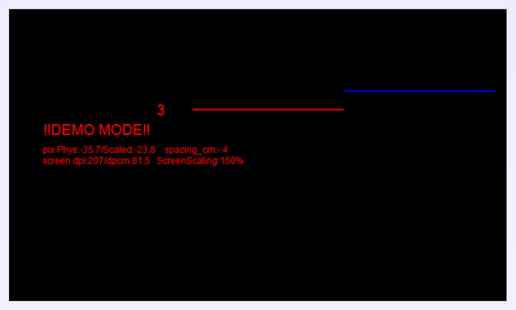

Fig. 4: Example of the VANTAN test. Subjects did 18 rounds of both the VAN and TAN test.

Fig. 5: Here, the participant is holding the vibration device, a hand massager, to their mastoid process.

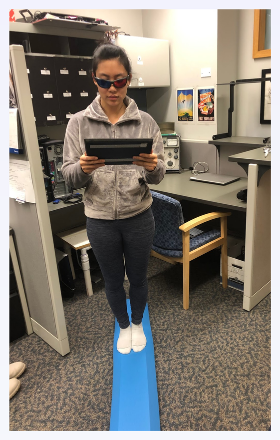

Fig. 6: Example of a participant doing the VANTAN test while standing on the foam beam (blue), unperturbed.

Challenges

1. How can we induce more effective, space-relevant methods of vestibular perturbation in the laboratory?
2. What analysis methods will work best for identifying relationships between ocular misalignment and postural sway?
3. What are ways to remove gravity and correct for device tilt on Earth that are still relevant in space?

Preliminary Analysis and Results

- Average VAN and TAN scores for each subject, as well as various postural sway parameters (examples shown in the figure below). Visual comparisons were made to assess corresponding trends in VAN/TAN and postural sway.

Fig. 7: Graphs of average VAN and TAN scores (top left and right) and various sway parameters (middle four graphs). Bottom left graph shows another way to visualize and compare data. Bottom right graph shows an example of sway area plotted out, which nicely characterizes the subject's movement

Upcoming Work

- Removal of gravity: We will begin removal of gravity and other artifacts (such as tilt) by decomposing the movement into its vector components and subtracting out the artifacts. Other techniques such as signal filtering will also be explored.
- Future analysis:
  - Exploring postural sway analysis in the frequency domain.
  - Experimenting with non-linear analysis techniques such as approximate entropy, detrended fluctuation analysis, etc. to further characterize postural sway.

References

[1] Shelhamer, et al. (2019) Assessment of Otolith Function and Asymmetry as a Corollary to Critical Sensorimotor Performance in Missions of Various Durations. (Grant No. 80NSSC19K0487)