Enhancing Sensorimotor Adaptability Training

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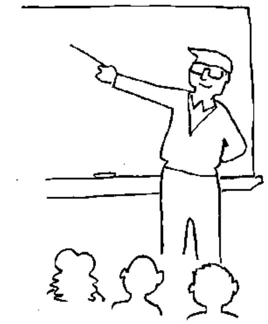
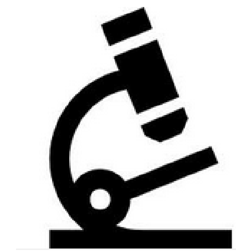
Neuroscience

SPACE LIFE SCIENCES
SUMMER INSTITUTE

Introduction





Internship Experience

- Article Review Experience:
  - European Archives of Oto-Rhino-Laryngology and Head & Neck (EAOR)
- Get Locomotion Study Going:
  - Review IRB.
  - Informed Consent / Layman's Summary.
  - Test Readiness Review (TRR).
  - Look at individual subjects' data from Peters et al., 2013.
  - Learn hardware & software.
    - GVS device.

Background

- Sensory discordance during gravitational transitions may affect planetary EVAs:
  - o ↓ locomotor stability.
  - o ↑ cognitive cost.
  - o ↑ metabolic cost.

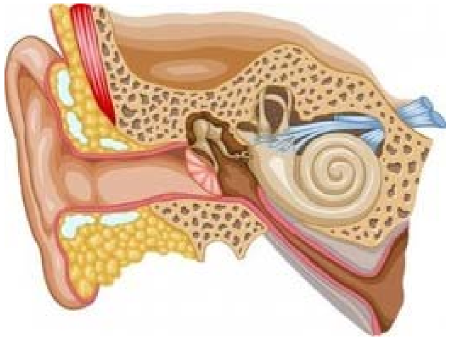
- Sensorimotor adaptability training may be used to mitigate these effects by challenging multiple sensorimotor systems.
  - o Brain “learns to learn” (adaptive generalization) and solves motor challenges better.
    - » More efficient at generating appropriate strategies.
      - ▪ ↑ adaptation tools ⇨ ↓ adaptation time.

(Mulavara et al., 2009; Peters et al., 2013)

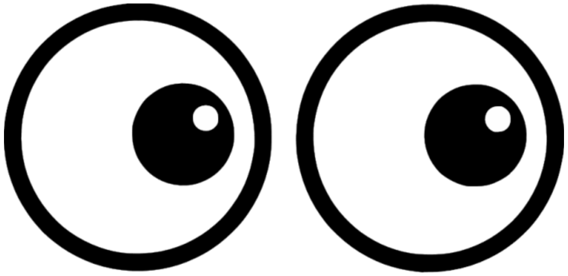
Background

- Sensory Weighting and Functional Performance

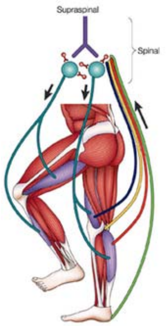
Vestibular System



Vision



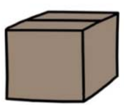
Somatosensation

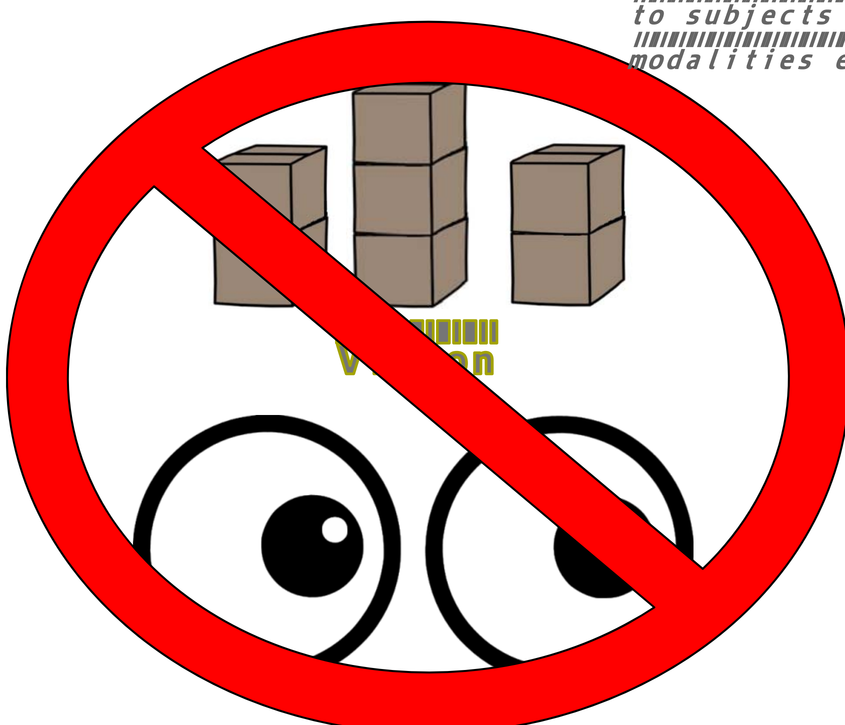


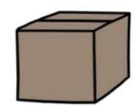
Background

- Sensory Weighting and Functional Performance

"We hypothesize that subjects who are more dependent on a single sensory modality and/or show reduced function within a given sensory modality will have reduced ability to adapt to a novel discordant sensory environment compared to subjects who use multiple sensory modalities equally."



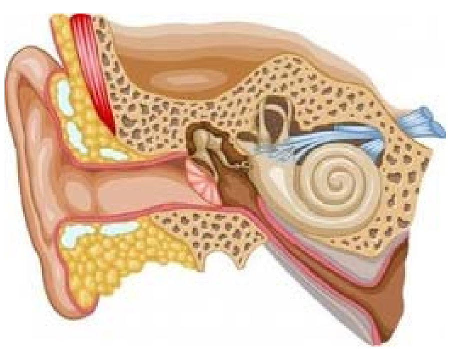




Vestibular System

Vision

Somatosensation

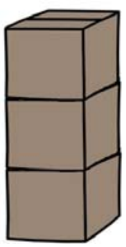


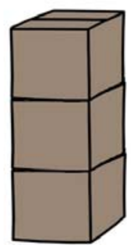
Brady et al., 2012

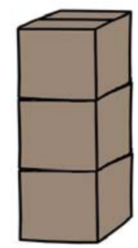
Background

- Sensory Weighting and Functional Performance

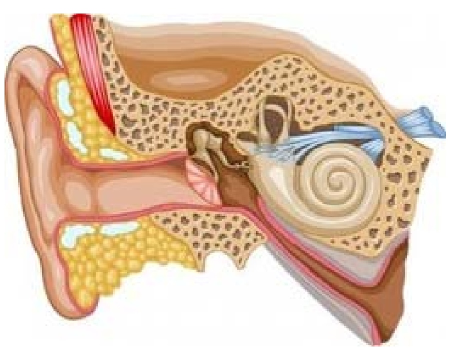
"We hypothesize that subjects who are more dependent on a single sensory modality and/or show reduced function within a given sensory modality will have reduced ability to adapt to a novel discordant sensory environment compared to subjects who use multiple sensory modalities equally."

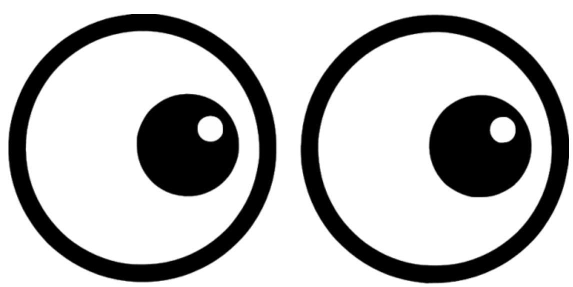






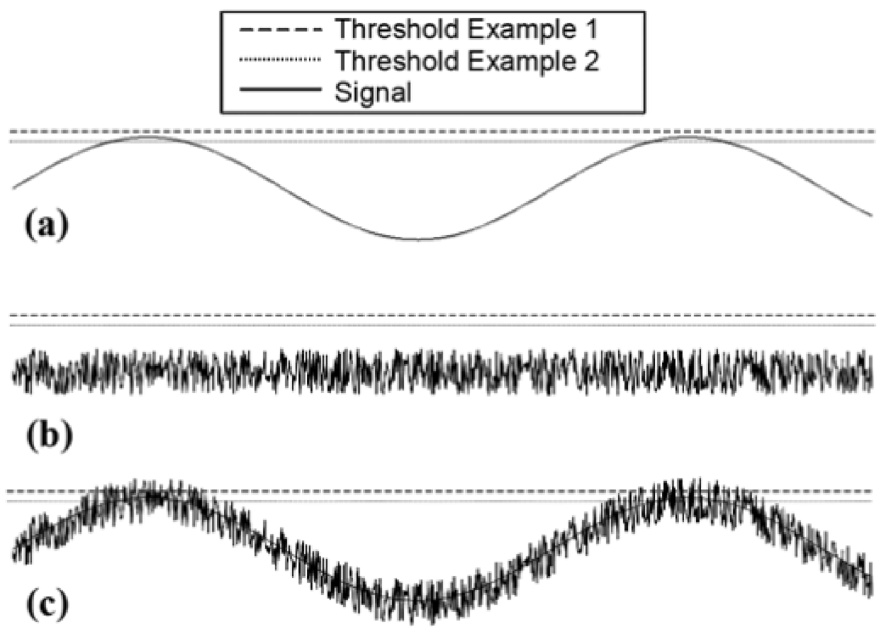
Vestibular System **Vision** **Somatosensation**





Background

- Stochastic Resonance (SR)
  - o Detection of weak input signals may be enhanced by addition of low levels of noise.
    - » Vestibular or proprioceptive.
    - » ↑ external cues.
    - » ↑ adaptability in sensorimotor adaptability training.

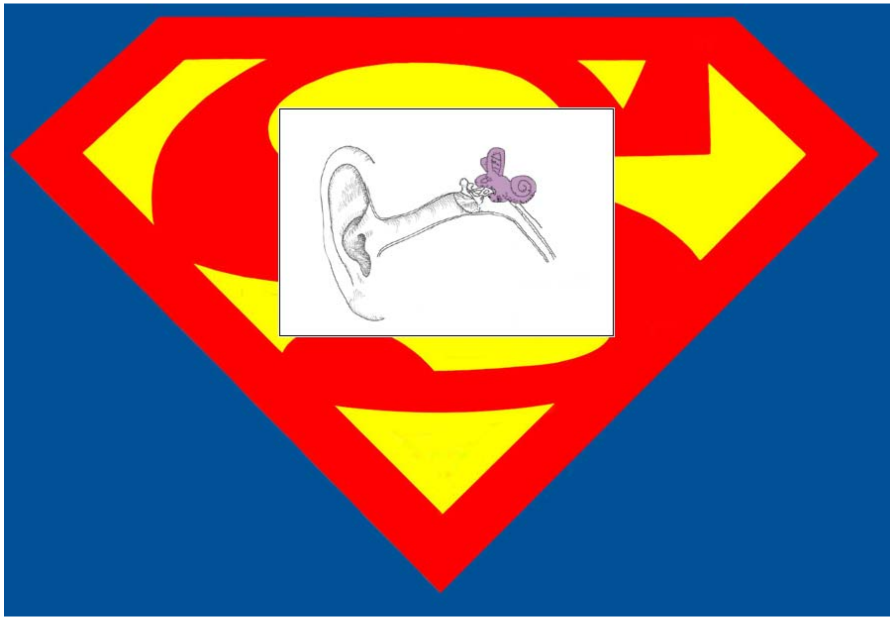


(Hijmans et al., 2008)

(Mulavara et al., 2011)

Background

- Purpose:
  - o Determine if SR can be used to improve individualized sensorimotor adaptability training programs by enhancing vestibular signal detection.



Methods

- Subjects:
  - Healthy (passed modified Air Force Class III physical).
  - ~10 in control group.
  - ~10 in experimental group (+SR).
  - Naïve to support surface perturbations.

Methods

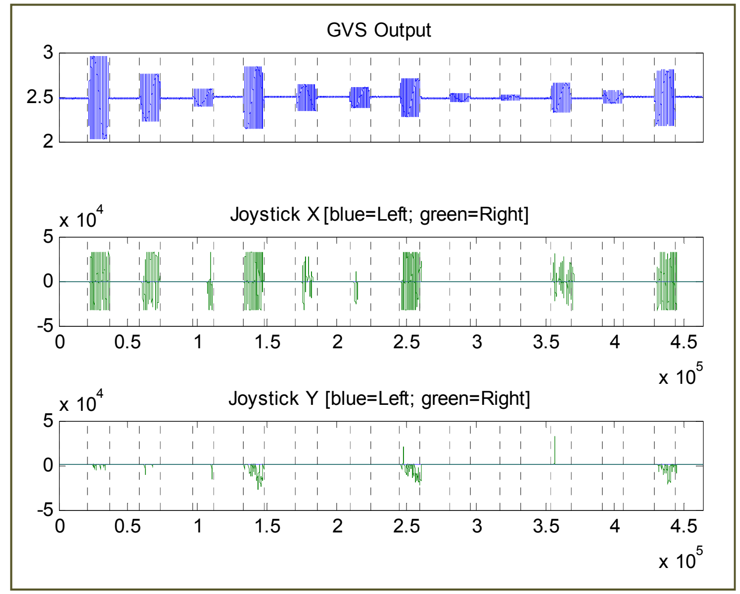
Equipment & Procedures:

o Vestibular Stimulus Device

» Maximum amplitude of 4 mA.

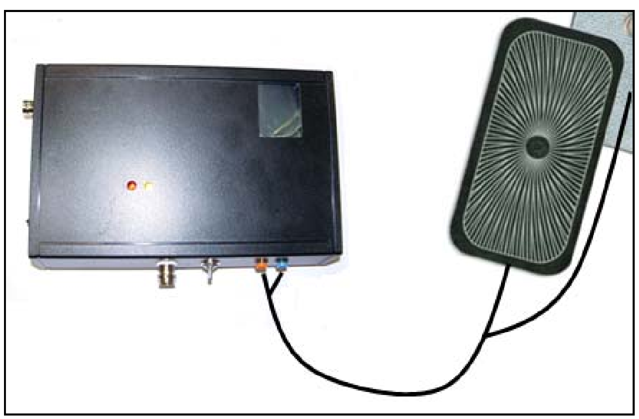
» Threshold Testing:

- Subject moves joystick with stimulus perception.
  - Sinusoidal signals (0-2,000 uA).
- Threshold and optimal stimulus are determined.

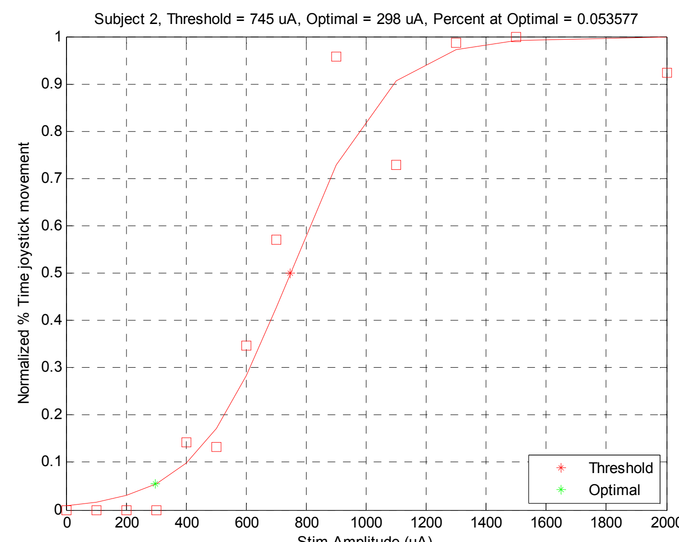


» Optimal amplitude of stimulus delivered is at 20-40% of individual's perceptual threshold.

- White Noise (100 Hz).

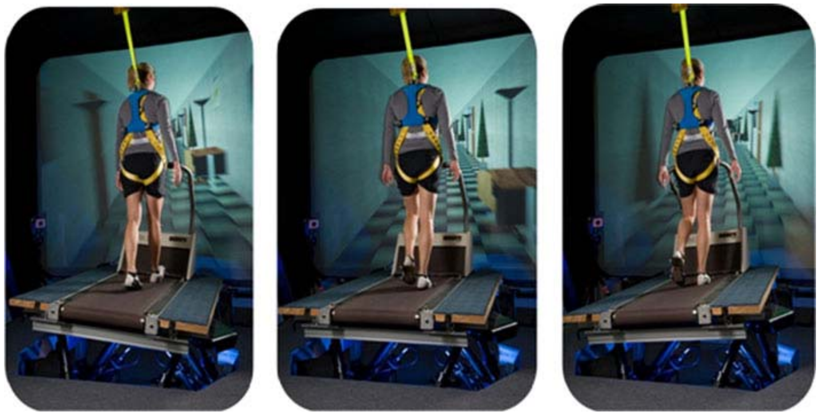


(Mulavara et al., 2011)



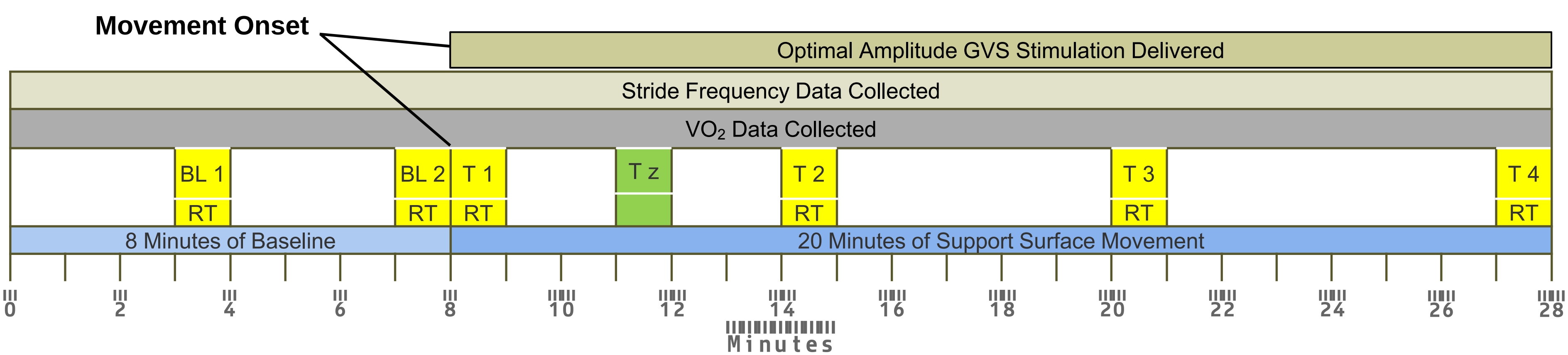
Methods

- Equipment & Procedures:
  - o Sensory Discordant Environment:
    - » Six Degree of Freedom Motion Base (Moog, East Aurora, NY):
      - ▪ 0.3 Hz continuous, sinusoidal, lateral motion.
        - • Started after 8 minutes of baseline walking.
    - » Treadmill (Quinton Model Q55, Philadelphia, PA):
      - ▪ 1.1 m/s for all subjects.
    - » Virtual Hallway:
      - ▪ 3.6 m x 2.6 m screen.
      - ▪ 2 m in front of subjects.
      - ▪ Forward translating.
        - • Perceptually matched to treadmill speed.



Methods

- Equipment, Procedures, & Analysis:
  - o Locomotor Instability ⇨ Stride Frequency:
    - » Collected continuously.
      - ▪ Foot switches (Motion Lab Systems, Baton Rouge, LA).
  - o Metabolic Cost ⇨ VO_2:
    - » Collected continuously.
      - ▪ Cosmed K4b2 (Cosmed USA Inc., Chicago, IL).
  - o Cognitive Cost ⇨ Reaction Time (RT):
    - » Collected at BL 1, BL 2, T 1, T 2, T 3, & T 4.
      - ▪ Custom LabView code (National Instruments, Austin, TX)
        - • 7 auditory tones presented at varied timing to reduce anticipation.
        - • Response via thumb switch.



Control Group?

RESEARCH ARTICLE

Adaptation in Locomotor Stability, Cognition, and Metabolic Cost During Sensory Discordance

BRIAN T. PETERS, RACHEL A. BRADY, CRYSTAL D. BATSON,
JAMIE R. GUINED, ROBERT J. PLOUTZ-SNYDER,
AJITKUMAR P. MULAVARA, AND JACOB J. BLOOMBERG

PETERS BT, BRADY RA, BATSON CD, GUINED JR, PLOUTZ-SNYDER RJ, MULAVARA AP, BLOOMBERG JJ. *Adaptation in locomotor stability, cognition, and metabolic cost during sensory discordance.* Aviat Space Environ Med 2013; 84:567–72.

Background: Locomotor instability may affect planetary extravehicular activities during the initial adaptation to the new gravitational environment. The goal of this study was to quantify the locomotor, cognitive, and metabolic effects of exposure to a discordant sensory environment. ***Methods:*** A treadmill mounted on a 6-degree-of-freedom motion base was used to present 15 healthy subjects with a destabilizing support surface while they walked. Dependent measures of locomotor stability, cognitive load, and metabolic cost were stride frequency (SF), reaction time (RT), and the volume of oxygen consumed ($\dot{V}o_2$), respectively. Subjects completed an 8-min baseline walk followed by 20 min of walking with a continuous, sinusoidal, laterally oscillating support-surface perturbation. Data for minutes 1, 7, 13, and 20 of the support-surface perturbation period were compared with the baseline. ***Results:*** SF, RT, and $\dot{V}o_2$ were significantly greater during support-surface motion than during the baseline walking condition and showed a trend toward recovery to baseline levels during the perturbation period. Results demonstrated that adaptation to walking in a discordant sensory environment has quantifiable and significant costs in SF, RT, and $\dot{V}o_2$ as shown by mean increases of 9%, 20%, and 4%, respectively, collected during the first minute of exposure. By the fourth minute of exposure, mean $\dot{V}o_2$ consumption had increased to 20% over its baseline. ***Discussion:*** We believe that preflight sensorimotor adaptation training paradigms will impart gains in stability and the ability to multitask, and might increase productive mission time by extending work time in extravehicular activity suits where metabolic expenditure is a limiting factor.

Keywords: human locomotion, sensory discordance, instability, perturbation, gait adaptation.

LOCOMOTOR ADAPTIVE responses and their associated costs interest us because astronauts encounter sensory discordance during gravitational transitions and must produce an adaptive locomotor response to walk after their return to Earth (19). Locomotor instability associated with gravitational transitions may affect planetary extravehicular activities during the initial adaptation period and might lead to decreased ability to multitask and increased metabolic costs. The goal of this study was to quantify the adaptive locomotor effects, as well as the cognitive and metabolic costs, of adaptation to walking in a discordant sensory environment.

After spaceflight, balance control and locomotor function are known to be compromised (5,18,19). Our laboratory is interested in sensorimotor adaptability training as a potential approach for mitigating these effects. An individual can enhance his or her ability to adapt by learning to solve a class of motor challenges rather than a specific challenge (4,20,25) because the brain "learns to learn" and becomes more efficient at generalizing appropriate strategies. Using this approach as the basis for a countermeasure, we believe that preflight treadmill training presented under novel and challenging sensorimotor conditions could expedite an astronaut's ability to ambulate safely on return to Earth or landing on the Moon or Mars.

Because some effects associated with sensory discordance are destabilizing enough to interfere with astronauts' mission objectives (during Earth-to-space transitions or space-to-partial-gravity transitions) and delay their return to activities of daily life (during space to Earth transitions), our laboratory develops training programs to expedite adaptation processes. Since gravitational transitions cannot be simulated in a laboratory, our approach has been to train individuals to solve a broad class of sensorimotor challenges—rather than any one in particular—so that they are better prepared to adapt to new ones, including those associated with gravitational change. By introducing new strategies and providing safe opportunities for subjects to experiment with and move between those strategies, we equip individuals with more adaptation "tools" and a broader range of experiences from which to draw. Reducing the adaptation time required after unexpected sensory cues are perceived facilitates efficient and safe gait patterns in discordant sensory conditions.

Training benefits stem from early stage (or fast) learning, typically seen within the same training session, and later stage (slower) learning, that normally results in long-term performance gains after repeated practice (23). The early and late state learning mechanisms are driven by two distinct neural systems (26). In this study, performance gains drew on an individual's early stage, or on-line "strategic" learning response. We previously performed a pre- and postflight functional assessment

From NASA Johnson Space Center, Houston, TX.

This manuscript was received for review in August 2012. It was accepted for publication in November 2012.

Address correspondence and reprint requests to: Brian T. Peters, M.S., Ph.D., Wyle Science, Technology & Engineering Group, 1290 Hercules Drive, Suite 120, Houston, TX 77058; brian.peters-1@nasa.gov.

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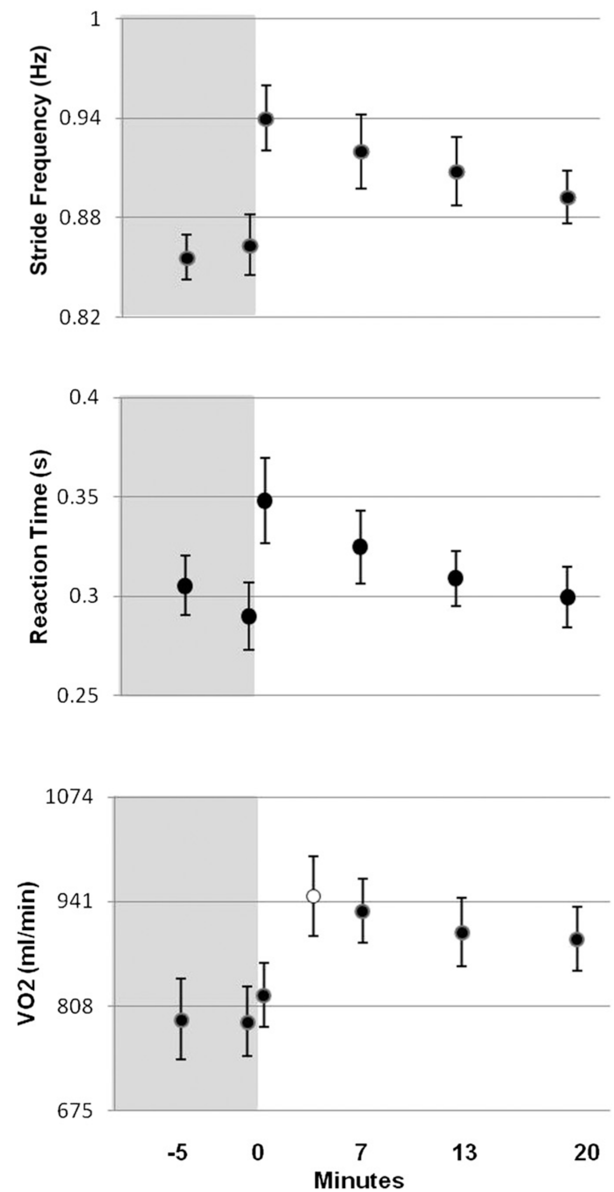
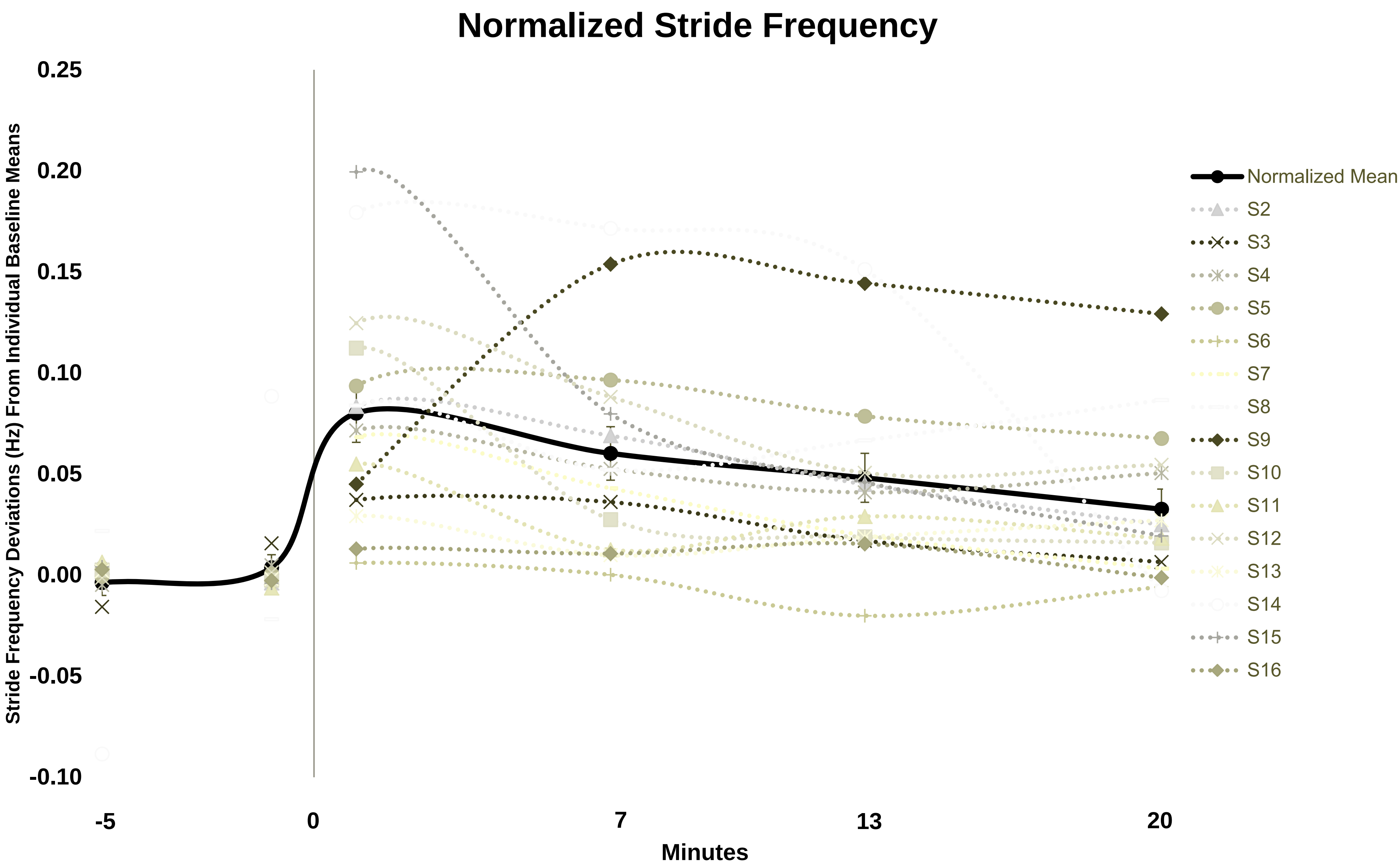


Peters et al., 2013

Methods

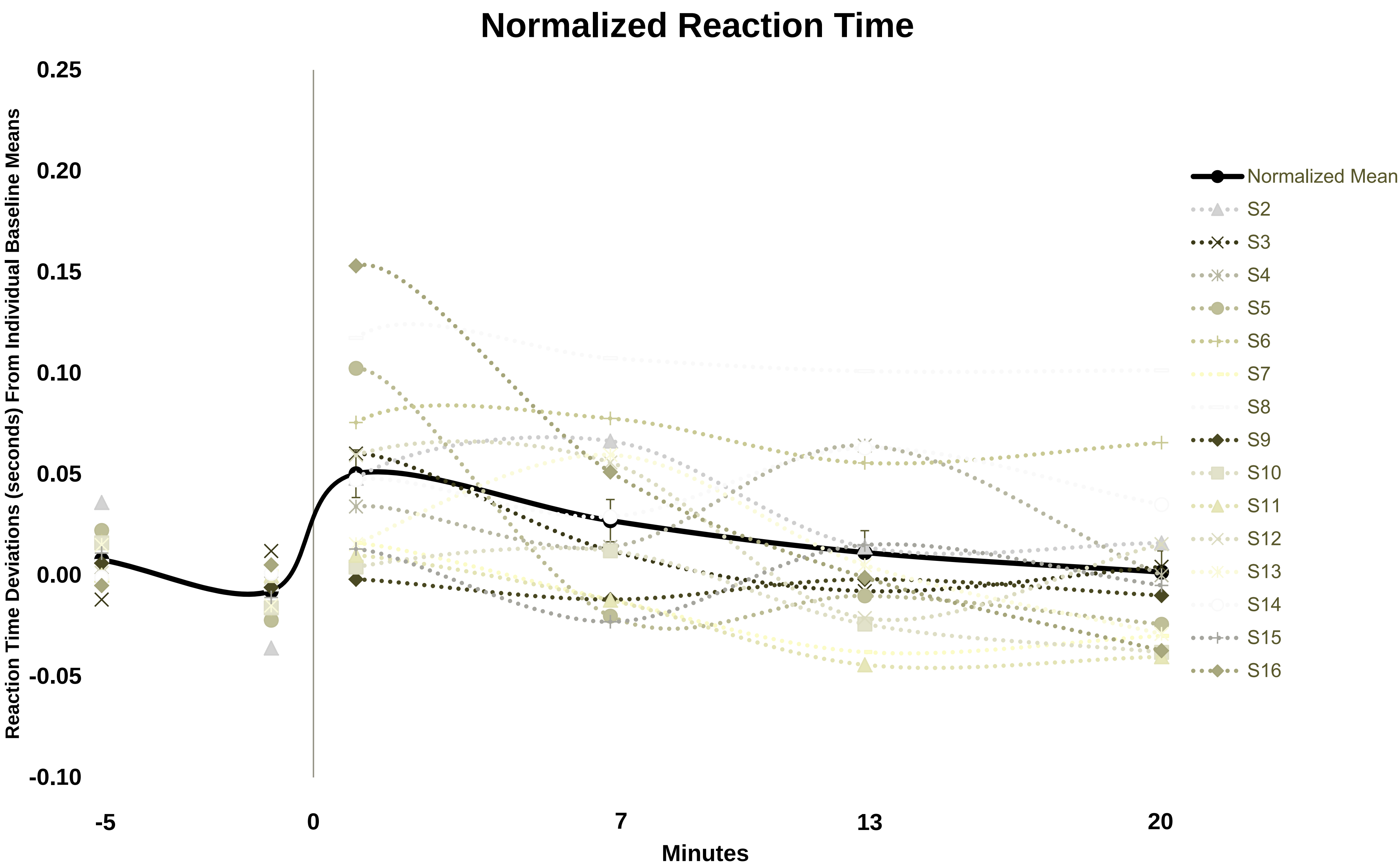
- Additional Analysis of Peters et al., 2013 Data:
  - My goals were to:
    1. Look at the individual subjects' responses to the discordant environment.
       - What is the variability across subjects?
    2. Examine relationships between the locomotor stability, metabolic cost, and cognitive ability parameters based off individual subject responses.

Results

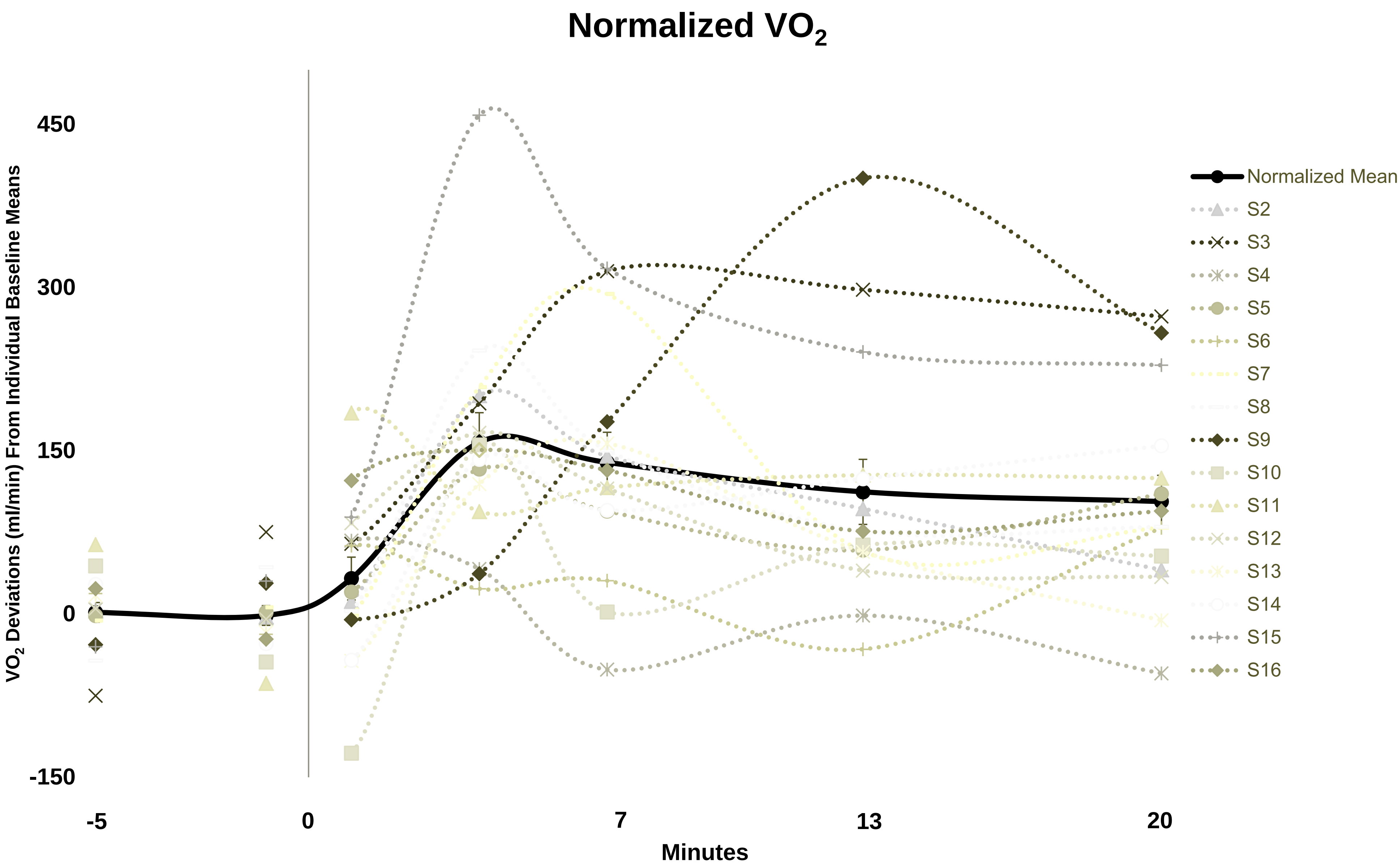


Normalized Stride Frequency
Stride Frequency Deviations (Hz) From Individual Baseline Means
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-5
0
7
13
20
Minutes
Normalized Mean
S2
S3
S4
S5
S6
S7
S8
S9
S10
S11
S12
S13
S14
S15
S16

Results


Normalized Reaction Time
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
Reaction Time Deviations (seconds) From Individual Baseline Means
-5
0
7
13
20
Minutes
Normalized Mean
S2
S3
S4
S5
S6
S7
S8
S9
S10
S11
S12
S13
S14
S15
S16

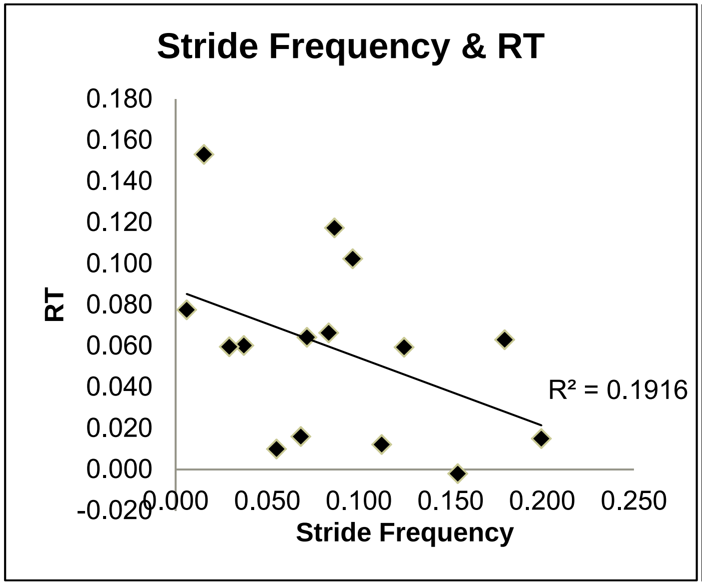
Results



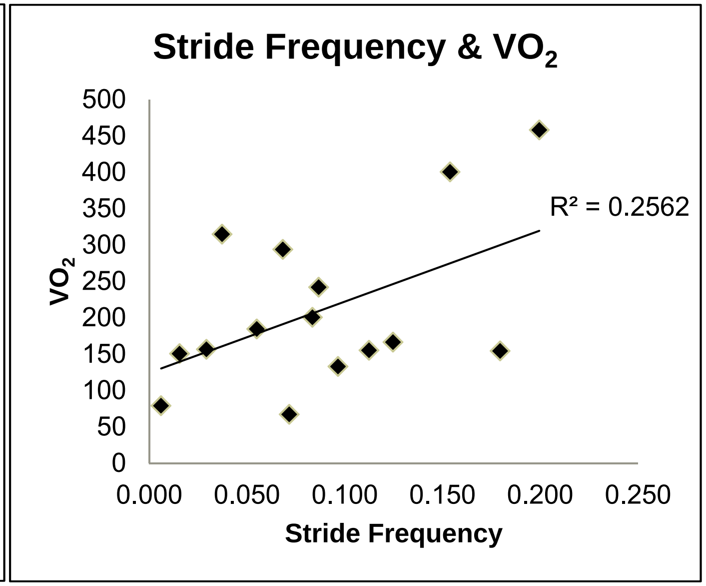
Normalized VO_2
450
300
150
0
-150
VO_2 Deviations (ml/min) From Individual Baseline Means
-5
0
7
13
20
Minutes
Normalized Mean
S2
S3
S4
S5
S6
S7
S8
S9
S10
S11
S12
S13
S14
S15
S16

Results

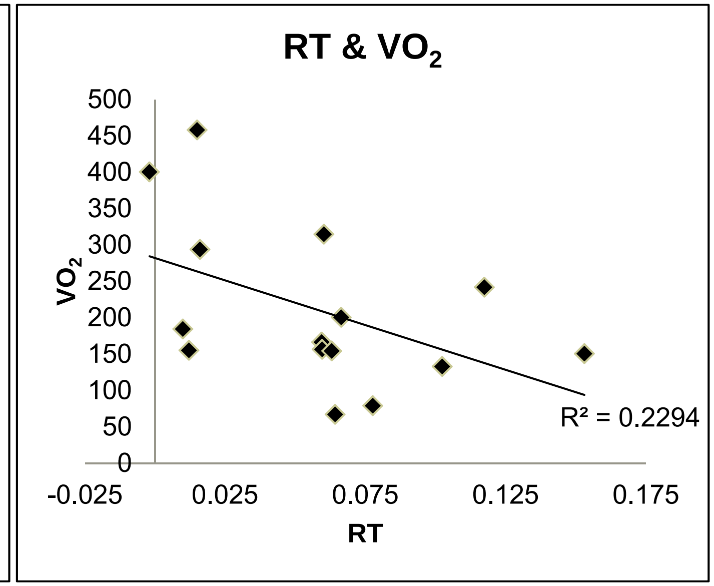
- Normalized Max Response Correlations:



Pearson's R = -0.438



Pearson's R = 0.506



Pearson's R = -0.479

- General Trend:
  - » ↑ Stride Frequency Resp. ⇔ ↑ VO2 Resp. ⇔ ↓ RT Resp.
    - No significant correlations though.

Take Home: Decreased locomotor stability is associated with increased metabolic cost and increased cognitive cost while adapting to novel sensory discordance.

Discussion

- What I learned:
  - Subjects display considerable variability in their responses to the discordant environment.
  - General trend in max response data between stride frequency, reaction time, and VO_2.
    - ↑ Stride Frequency Resp. ⇔ ↑ VO2 Resp. ⇔ ↓ RT Resp.
- Contributions to NASA's knowledge base:
  - Adaptation to sensory discordance can incur tradeoffs in locomotor, metabolic, and cognitive abilities.
    - Decreased locomotor stability is associated with increased metabolic cost and increased cognitive cost while adapting to novel sensory discordance.
- Uses for future research/mission planning:
  - Determine if vestibular SR helps improve adaptation to a novel sensory discordant environment.
  - Design individual sensorimotor adaptability training programs to promote multisensory reliance in individuals to enhance ability to adapt.

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  - Erin Caldwell
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- Rahul Goel
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NASA