ESTIMATION OF OPTIMAL STIMULUS AMPLITUDE FOR BALANCE TRAINING USING ELECTRICAL STIMULATION OF THE VESTIBULAR SYSTEM

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INTRODUCTION

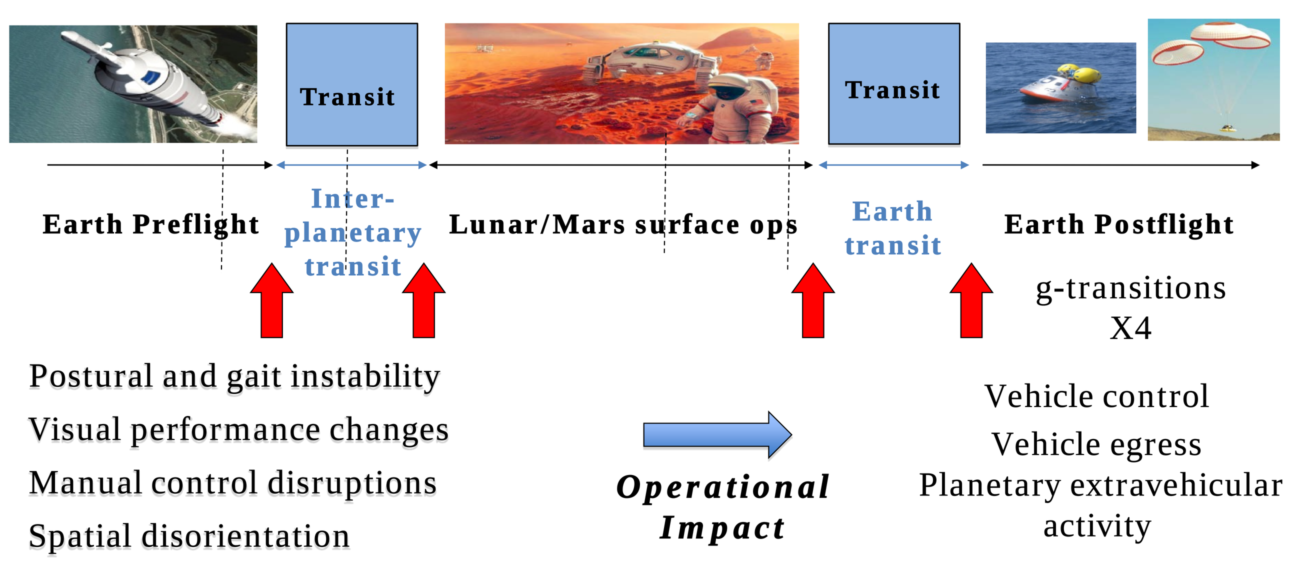

Figure 1: Sensorimotor performance profile during Inter-planetary missions.

- Inter-planetary missions have 4 transition periods that require sensorimotor adaptation to altered gravity environment.
- Performance decrements occur during and after g-transition.
- Sensorimotor Adaptability Training might help alleviate performance deficits by exposure to varying sensory challenges during balance tasks (Bloomberg, 2015).
- Supra-threshold Stochastic Vestibular Stimulation (SVS) can be used to provide such a challenge by disrupting vestibular inputs, to facilitate use of more veridical information from other inputs, e.g., vision and somatosensory inputs.
- The minimum SVS amplitude for training has not yet been identified.

Objective

The goal of this study was to determine the minimum, safe SVS level useful for studies of sensorimotor adaptability training.

METHODS

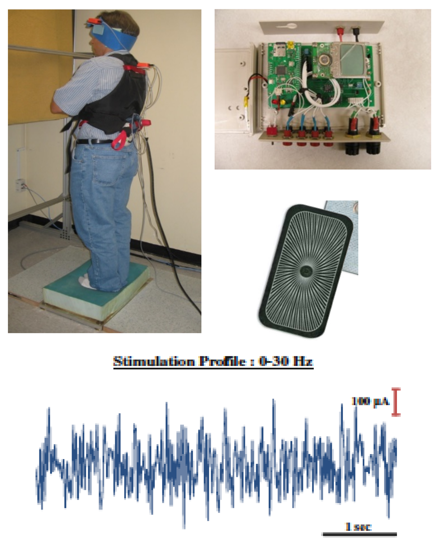

Figure 2: Experimental setup.

Subjects: 13 healthy young subjects (7 male).

Balance task: Standing on 10-cm- medium-density foam, feet together, arms crossed, eyes closed. A "fall" was if the subject: spread arms, opened eyes, or moved legs.

Stochastic Vestibular Stimulation (SVS): Electrical stimulation was applied to the vestibular system through 2" x 4" electrodes placed over the mastoid process using a constant current stimulator. Trial durations were up to 44 s with two 21.5 sec *baseline* and *stimulus* periods. At *baseline* periods subjects had no stimulation. During *stimulus* periods subjects had 0-30 Hz white noise bipolar stimulation signals at one of 10 amplitude ranges: 0 to ±4.5 mA, in increments of ±0.5 mA. Trial order was randomized.

Data Analysis:

Balance performance for each of the control and experimental trials was characterized during *baseline* and *stimulus* period using the root mean squares (RMS) of six parameters measured in the medio-lateral direction: force (Fy), roll moment (Mx), linear acceleration for the head (Hay) and trunk (Tay), roll angular velocity for the head (Hrv) and trunk (Trv).

Control trials, have 0 mA signals during both periods while experimental trials have 0 mA during the *baseline* period and one of the non zero amplitude signals during the *stimulus* period.

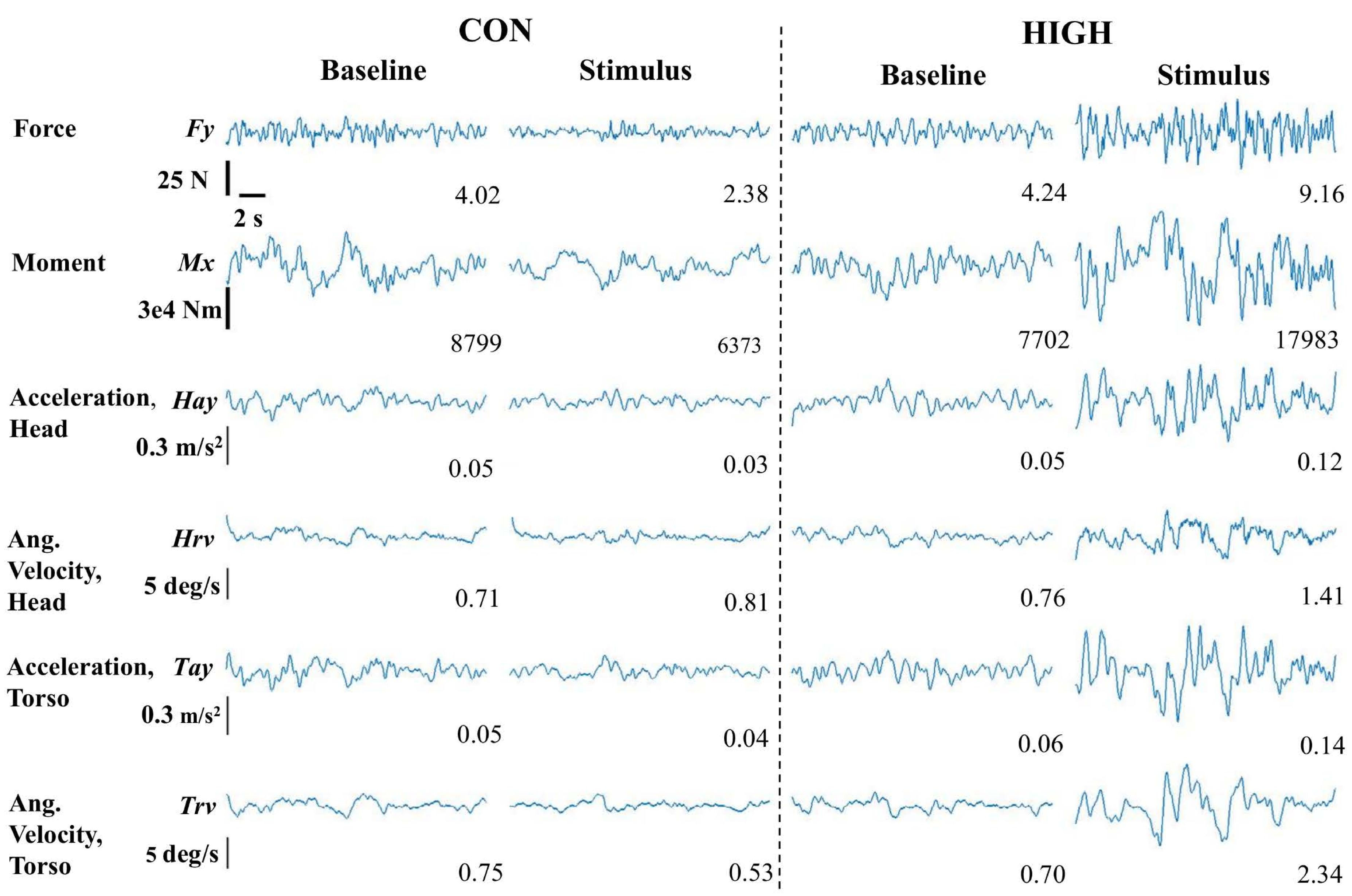

Figure 3: The six parameters for one subject for *baseline* (0 mA) and *stimulation* periods during Control (CON, 0 mA) and High amplitude (HIGH, ±4.5 mA) trials. RMS values indicate that SVS challenges balance control for HIGH trials compared to CON trials.

Minimum SVS level characterization

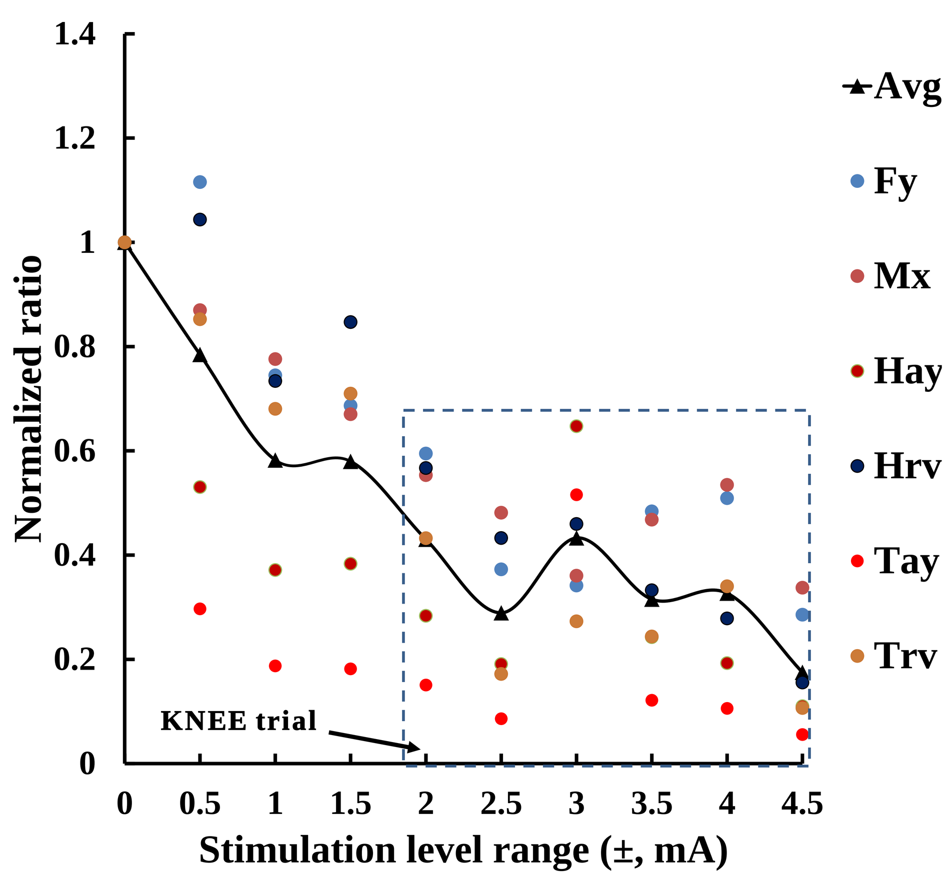

Figure 4: Normalized ratio data for one subject of 6 parameters and the average of those ratios (black triangles) at different stimulus levels.

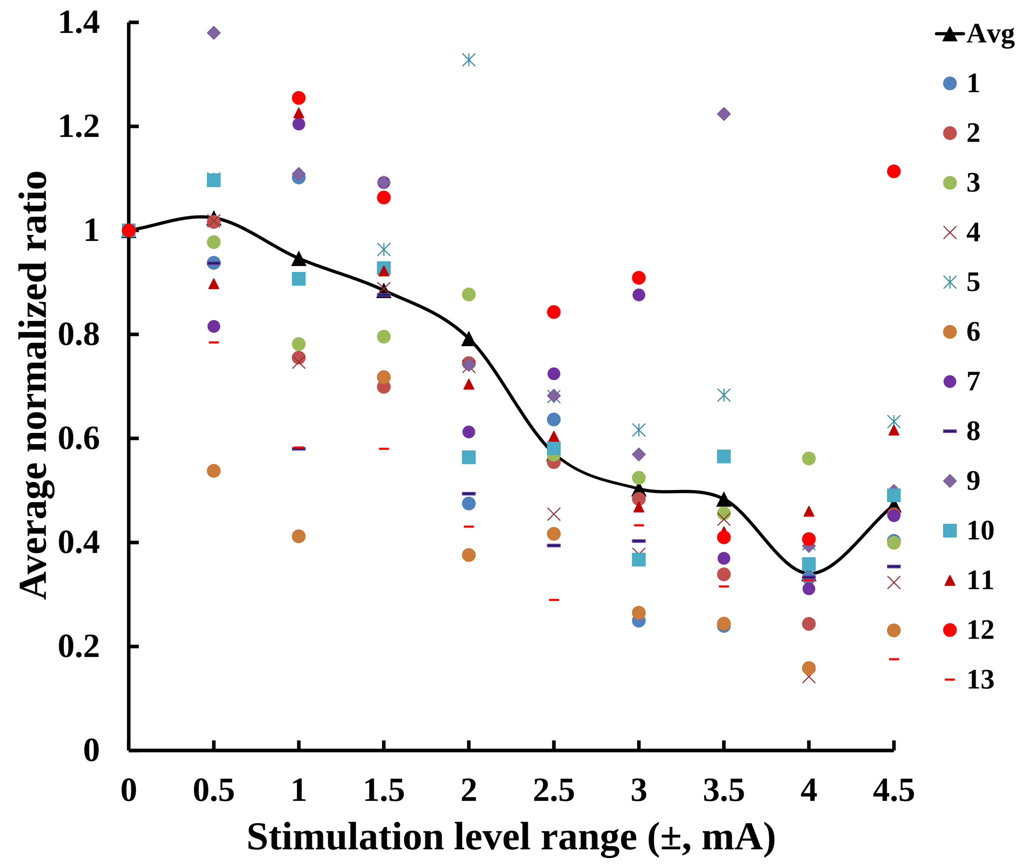

Figure 5: Average normalized ratio data across 6 parameters for all 13 subjects including the average across subjects (black triangles) at different stimulus levels.

For each parameter, the ratio for *stimulus* period to *baseline* period for the CON trial was normalized with the ratio for all experimental trials (Figure 4). These ratios were used to calculate the minimum SVS level at which balance performance is significantly degraded compared to no stimulation so further increase in SVS intensity does not lead to further degradation.

Minimum SVS level was tested iteratively until the slope of linear fits, across the normalized ratios going backwards starting from the HIGH trial, was significantly different than 0. The last stimulation level after which there is no further degradation in balance performance was defined as the KNEE trial, e.g. in Figure 4, using stimulation levels which are greater than and equal to ±2.0 mA, and the corresponding average normalized ratios (black triangles) give a non-significant slope. This process was repeated for each subject. See Figure 5.

RESULTS

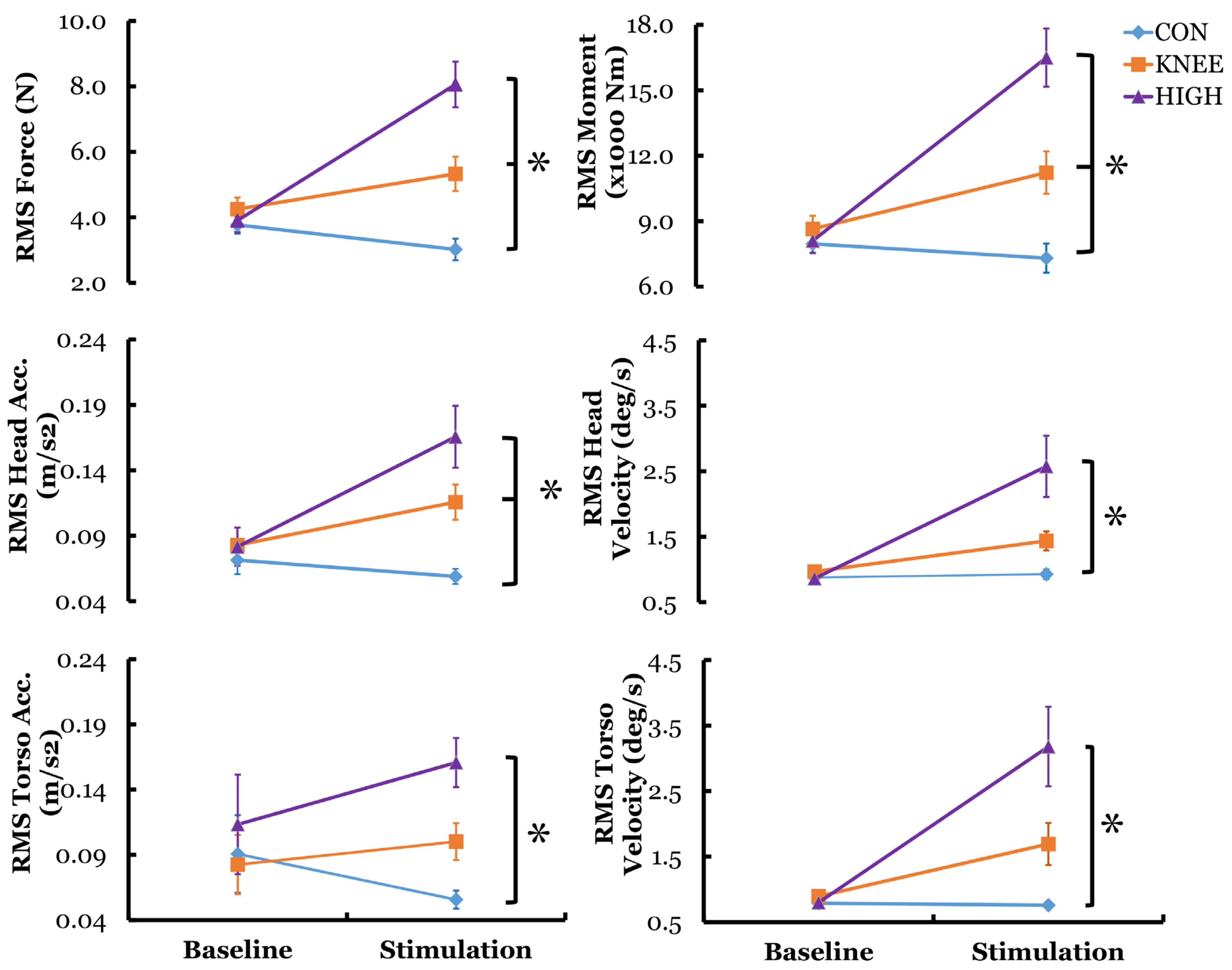

Figure 6: Average (±SEM) RMS values for the six parameters during *baseline* and *stimulus* periods of CON, KNEE and HIGH trials (n=13).

Figure 6 shows average values for the six parameters across PERIODs (baseline & stimulation), and TRIALs (CON, KNEE, HIGH).

ANOVA showed significant differences for all variables except for Tay (p<0.05, Table 1). The significant ANOVA on the ratios of stimulation by baseline (p<0.05) and post- hoc Bonferroni comparisons showed differences between the three TRIAL conditions (p<0.05). See Figure 6 where "*" denotes significant difference between the indicated TRIALs.

The average (±SEM) of KNEE stimulus intensity, was found to be 1.8 (±0.13) mA.

Across all 6 parameters, SVS resulted in an average decrement in the range of 31%-138% at the KNEE stimulus intensity based on individual subject responses.

Table 1: Results of repeated measures ANOVA univariate tests for each of the six parameters.

Parameter	Trial	Period	Trial*Period
Force	F(2,24) = 43.9, p<0.001*	F(1,12) = 25.5, p<0.001*	F(2,24) = 72.6, p<0.001*
Moment	F(2,24) = 33.3, p<0.001*	F(1,12) = 33.7, p<0.001*	F(2,24) = 51.3, p<0.001*
Head Acceleration	F(2,24) = 5.5, p<0.023*	F(1,12) = 13.4, p<0.003*	F(2,24) = 7.90, p<0.007*
Head Velocity	F(2,24) = 11.0, p<0.004*	F(1,12) = 17.1, p<0.001*	F(2,24) = 15.2, p<0.001*
Torso Acceleration	F(2,24) = 2.8, p<0.092	F(1,12) = 0.56, p<0.468	F(2,24) = 2.30, p<0.140
Torso Velocity	F(2,24) = 13.2, p<0.001*	F(1,12) = 13.1, p<0.004*	F(2,24) = 15.4, p<0.001*

Table 2: Average (±SEM) percent decrements in ratios of *stimulation* by *baseline* at the KNEE intensity level with respect to the ratios at CON.

Parameter	% Decrement
Force	62.68±13.97
Moment	47.46±17.37
Head Acceleration	84.25±32.96
Head Velocity	31.52±13.76
Torso Acceleration	138.11±79.73
Torso Velocity	89.58±38.26

CONCLUSIONS

1. **The minimum stimulus intensity for disrupting balance performance without further degradation was ±1 to ±2.5 mA across subjects.**
2. **Training using supra-threshold SVS stimulation as a sensory challenge in preflight Sensorimotor Adaptability Training may be useful. Inter-individual differences in response to SVS can help customize the training paradigms using the minimal dosage required.**

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