# The Interplay Between the Three Sensory Modalities During Standing

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## BACKGROUND

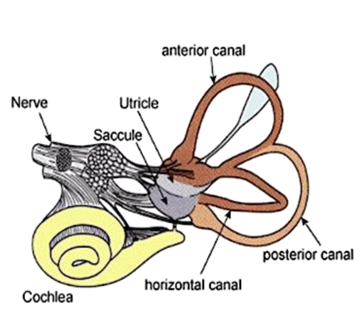
### Control of human upright stance

Sensory input **from multiple sources** is necessary

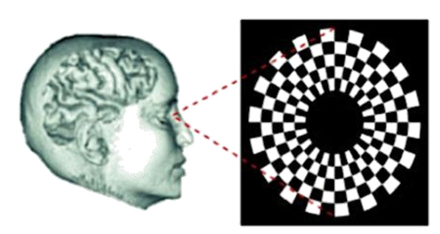
- ✓ to detect center of gravity excursions
- ✓ to generate appropriate muscle responses for upright stance control.

### Visual, vestibular and proprioceptive modalities

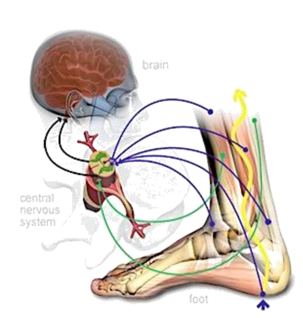
**Estimation of body position/velocity** (i.e., self-motion) **is heavily dependent upon the integration of information from multiple sensory modalities.**




vestibular modality



visual modality



proprioceptive modality

### Sensory reweighting

Numerous studies have demonstrated that the integration of sensory information (i.e., sensor fusion) appears to be dynamically regulated to adapt to changing environmental conditions and the available sensory information, a process referred to as "sensory reweighting".

Sensory reweighting is the process through which the nervous system changes the "emphasis" of a particular sensory input due to neurological injury or when environmental conditions change.

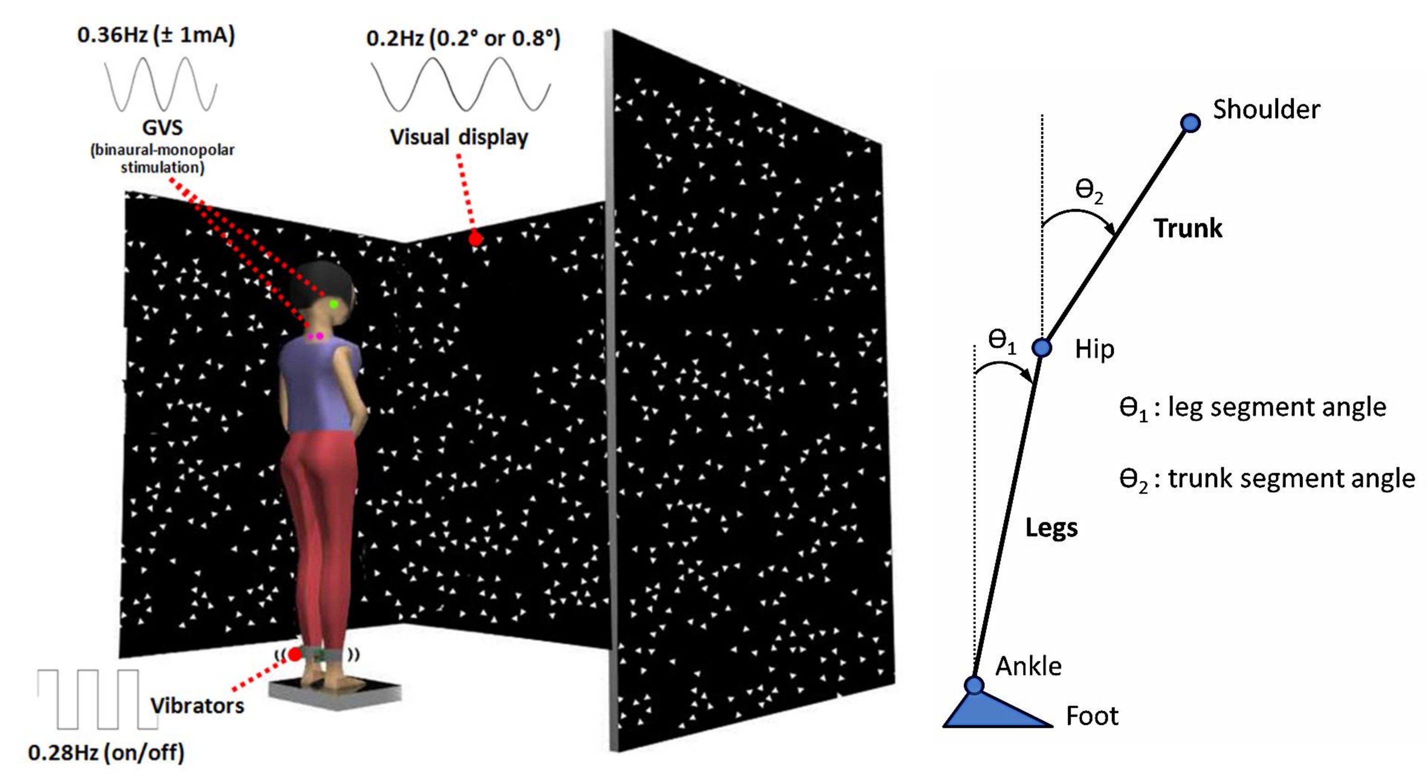
## RESEARCH PURPOSE

**Q: Does the CNS upweight both proprioceptive and vestibular modalities when vision is downweighted** (and vv) **?**

**Q: Does vestibular information serve as a reference to adjust emphasis on vision and proprioception?**

We **simultaneously perturbed visual, vestibular and proprioceptive modalities** to understand the interplay between all three modalities so that overall feedback remains suited to stabilize upright stance.

## METHODS




### STIMULI

**Visual stimulus**

- 0.2 deg and 0.8 deg rotation (pitch) about ankle axis
- stimulus frequency : 0.2 Hz

**Vibration**

- 80Hz vibration at both Achilles' tendons
- on/off to approximate a square-wave periodic stimulus
- stimulus frequency : 0.28 Hz

**Galvanic Vestibular Stimulation (GVS)**

- binaural-monopolar GVS
- ±1mA sinusoidal galvanic stimulus
- stimulus frequency : 0.36 Hz

**SUBJECTS:** **10 healthy young participants** *(28.2±4.6yrs)*

**EXPERIMENT SETUP:** **4 conditions, 135 sec/ trial, 7 trials in each condition**

- **L-V-G** : low amplitude vision – vibration – GVS
- **L-G** : low amplitude vision – no vibration – GVS
- **H-V-G** : high amplitude vision – vibration – GVS
- **H-G** : high amplitude vision – no vibration – GVS

**KINEMATICS:** **leg segment angle & trunk segment angle**

**ANALYSIS:** **Frequency response functions (FRFs)**

- **The FRF, $H_{xy}(f)$, is the CSD divided by the PSD of the input.**
- **PSD** – power spectral density
- **CSD** – cross spectral density
- **Gain** : the absolute value of the FRF, $H_{xy}(f)$
- **Phase** : the argument of the FRF, $H_{xy}(f)$, converted to degrees

**STATISTICAL ANALYSIS:**

- **Two way repeated-measures ANOVA** *(for visual stimulus and GVS)*
  visual amplitude (low vs. high amplitude) × vibration *(vibration vs. no vibration)*
- **Maximum-likelihood method** *(for vibration)*

## RESULTS

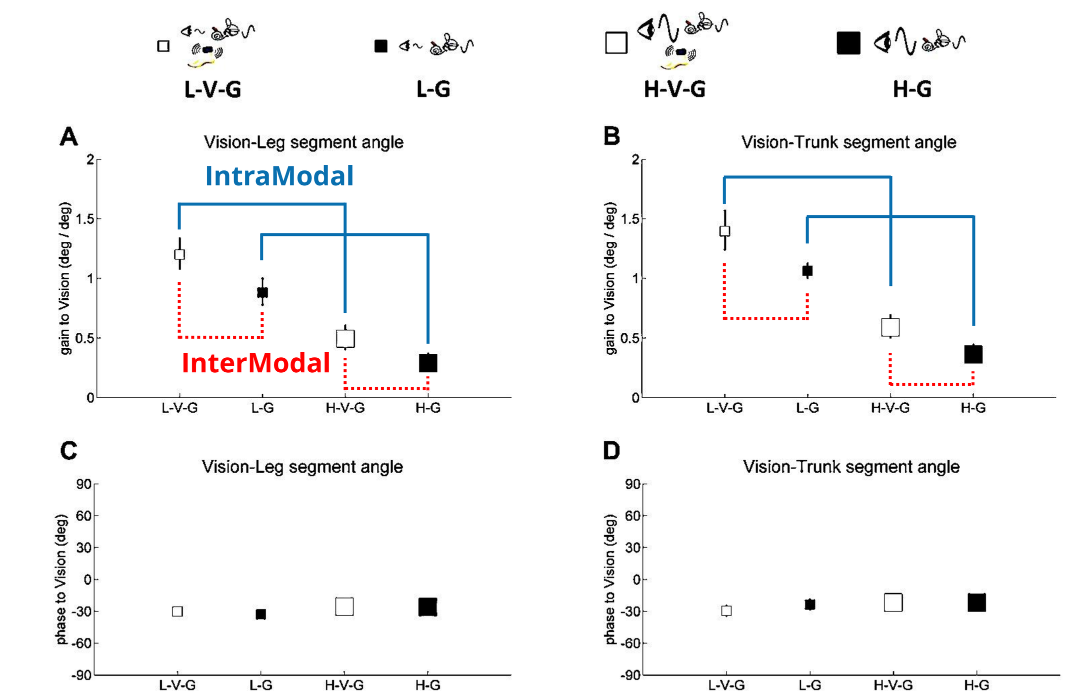



**Figure 1. Gain and phase of segment angles relative to vision**

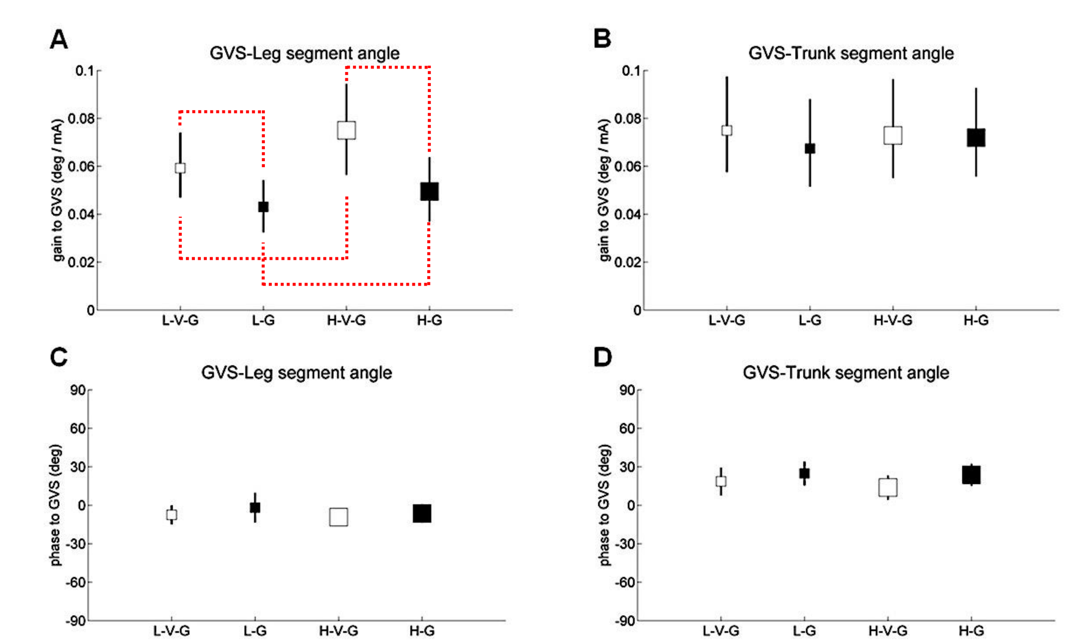



**Figure 2. Gain and phase of segment angles relative to GVS**

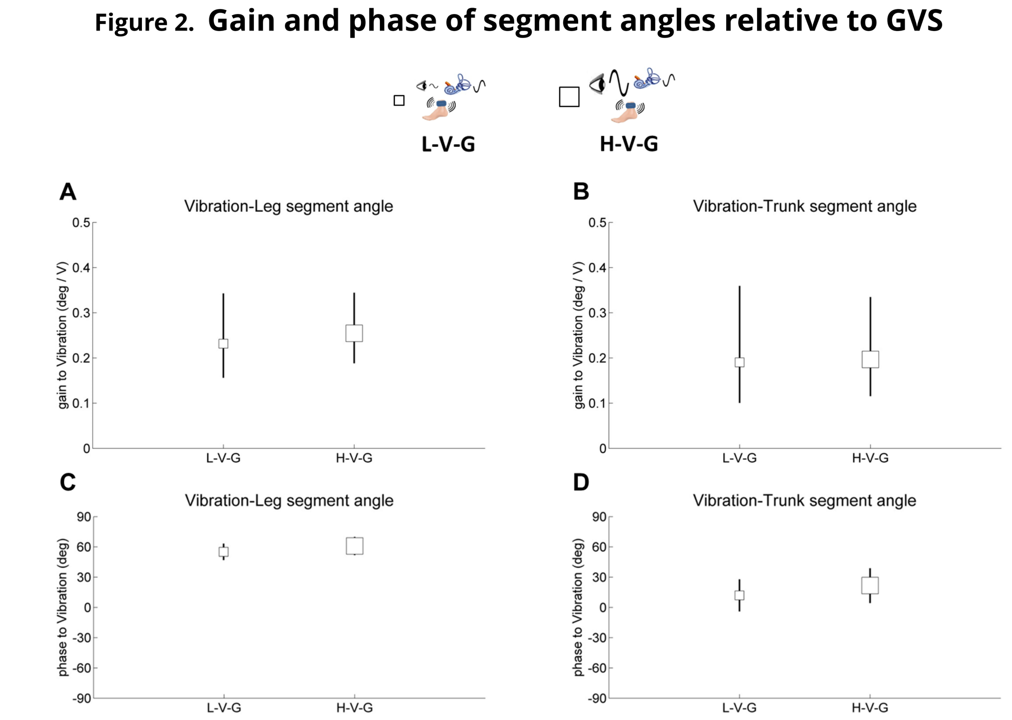



**Figure 3. Gain and phase of segment angles relative to vibration**

### GAIN RESPONSES: Vision low to high amplitude

Conditions: **L-V-G to H-V-G** and **L-G to H-G**

**IntraModal Visual Downweighting** *(Fig 1A-B)*

➡ **decrease leg/trunk gain relative to vision**

**InterModal Vestibular Upweighting** *(Fig 2A)*

➡ **increase leg gain relative to GVS**

- Reflects compensation for visual downweighting.
- No effects for trunk gain relative to GVS *(Fig 2B)*
- No intermodal effects on vibration gain *(Fig 3)*

### GAIN RESPONSES: Vibration off to on

Conditions: **L-G to L-V-G** and **H-G to H-V-G**

**InterModal Visual Upweighting** *(Fig 1A-B)*

➡ **increase leg/trunk gain relative to vision**

**InterModal Vestibular Upweighting** *(Fig 2A)*

➡ **increase leg gain relative to GVS**

**These intermodal effects suggest ...**

vibration disrupts proprioceptive information at the foot/ankle, forcing the nervous system to compensate by upweighting vision and vestibular information.

### PHASE

- ✓ **no differences across conditions**
- ✓ **absolute differences relative to modality**

## CONCLUSION

Results showed **a clear intramodal visual effect, indicating a de-emphasis on vision when visual amplitude increased.**

An **intermodal visual-proprioceptive reweighting effect** was observed with the addition of vibration, which is thought to change proprioceptive inputs at the ankles, forcing the nervous system to rely more on vision.

Similar **intermodal effects for visual-vestibular reweighting** were observed, suggesting that **vestibular information is not a "fixed" reference, but is dynamically adjusted in the sensor fusion process.**

This is the first time, to our knowledge, that the interplay between the three primary modalities for postural control has been clearly delineated, illustrating a central process that fuses these modalities for accurate estimates of self-motion.

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