Sensory-motor integration during locomotion with the use of virtual reality – the effect of virtual incline

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Background

- The "Internal Model of Gravity" (IMG) seems to regulate locomotion adaptations to inclined surfaces during walking. It is fed by three sensory inputs:
  - *Vestibular*
  - *Proprioception* } Body-based cues (gravity dependent)
  - *Vision*
- While walking and transitioning to a new inclination, visual cues temporarily predominate behavior over body-based cues, as recently observed in gait speed modulations caused during virtual reality (VR)-based experiments exposing the participants to incongruency between physical and visual inclinations (e.g. treadmill remains leveled while the visual scene transitions upward/downward)[1].
- Leg muscles show inclination-specific patterns of activation with changes in the timing of peak activity and magnitude throughout the gait cycle.

Objectives

Gain further insights about the psychophysical and physiological aspects of the role of vision in modulating gait while transitioning to inclined walking.

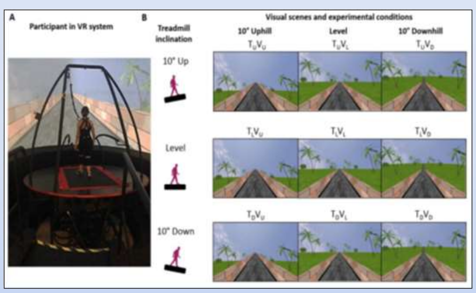
- How does vision influence the internal model of gravity and affect gait?
- Are muscle activation patterns driven by vision?

Hypothesis

- Muscle activation pattern during a visual-only simulated virtual environment will be similar to that seen during real incline walking.
- The intensity of gait modulation (i.e., change in gait speed) seen in response to visual illusion of inclined walking is correlated with visual dependency level as measured independently.

Methods

- 12 healthy adults (26.53±3.09 years, 6 males).
- A fully immersive VR system containing a platform with an embedded treadmill that operates in a self-paced mode. Simultaneous motion capture system tracked the 3D coordinates (41 body passive markers).
- Conditions**:** Inclination of the treadmill (**T**) and/or visual scenes (**V**) transitioned to 10° uphill (**U**), remained level at 0° (**L**) or transitioned to -10° downhill (**D**).



Experimental setup. Rows: treadmill (T) inclination, columns: visual scene (V) inclination. Congruent conditions between treadmill and vision are on the diagonal (T_UV_U- both uphill, T_LV_L- both level, and T_DV_D- both downhill). The other conditions are physical-visual incongruent.

Surface electromyography (EMG)

Tibialis Anterior (TA) Gastrocnemius (GC), Rectus Femoris (RF) and Biceps Femoris (BF).

Rod and frame test

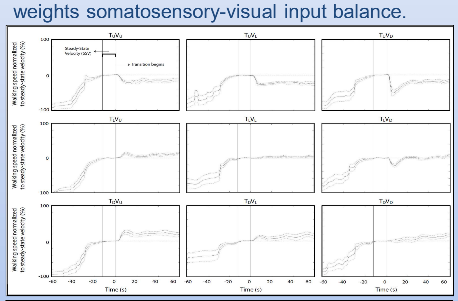
Task: Align the rod vertically to the true horizon, while ignoring the frame's orientation.

28 trials were presented in which the frame was initially at one of seven possible random angles: 0/±10/±20/±30 degrees; the initial angle of the rod was also random. For each participant, the mean position error for each of the 7 frame angles was calculated. Data from all participants were grouped by the frame angle and analyzed by repeated-measures ANOVA.

Results

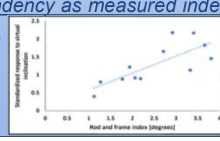
Behavioral effects of walking in physical and virtual inclinations

- Vision governs walking speed adaptation immediately after transition to virtual inclinations. Participants either slowed down to counter the gravitational 'boost' in downhill virtual inclination or sped up to counter the expected gravity resistance in uphill virtual inclination.
- When only downward visual inclination is presented gait speed decreased by 25±15% (peak at 8±2 sec.). When only upward visual inclination is presented gait speed increased by 18±8% (peak at 10±2 sec).
- The effect subsides after the participant re-weights somatosensory-visual input balance.



Adaptation of walking speed. Average self-paced walking speed relative to steady-state velocity for each condition. Time zero demarcates the end of the steady-state velocity period, after which the transition of the treadmill and/or visual scene occurred for five seconds. Dotted line represent standard error.

Speed related behavioral effects were correlated with visual dependency as measured independently psychophysically.

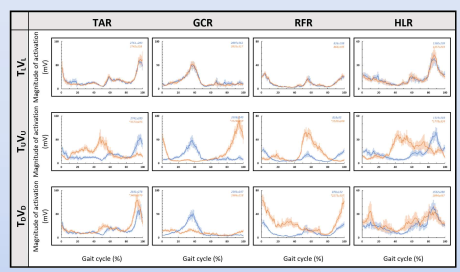


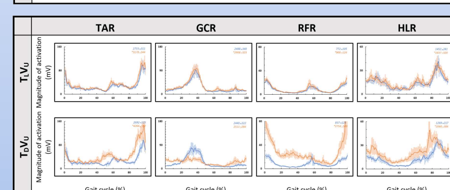
Changes in speed during incongruent conditions (T_LV_U, T_LV_D, T_DV_U, T_UV_D) vs. psychophysically measured visual dependency. A significant correlation (Spearman Rho =0.790, p= 0.002) indicates that a high visual dependent score, as measured by the rod and frame test are implicated with a larger change in walking speed due to a visually simulated virtual inclination. Each circle represents data from one participant.

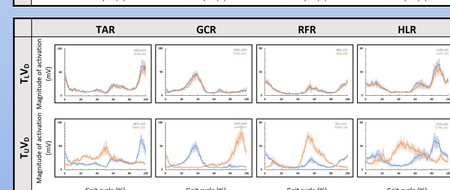
Results (Cont.)

Adaptations of leg muscle activation during inclined walking

- EMG temporal patterns were well differentiated between different physical inclinations, though they were not affected by virtual inclinations.
- Muscle activation intensity was affected by virtual inclinations, consistent with gait speed changes triggered by these conditions, and in trials where only walking speed was changed (data not shown).







Average pattern of muscle activation throughout the gait cycle. Abscissa: percentage of the gait cycle, Ordinate: magnitude of activation. Blue and orange lines depict activity pre and post transition, Shaded areas represent standard error. On the right upper corner blue and orange numbers represent the average summation of muscle activation for pre and post transition, respectively.

Conclusions

- Visual cues modulate gait as behaviorally expressed by changes in walking speed.
- Muscle activation pattern during the gait cycle is dominated by body-based cues, regardless of visual signaling about walking on an inclined surface.
- During leveled walking, the intensity of muscle activity reflects walking speed, rather than visually directed behavior (i.e., inclination illusion).

References

1. Cano Porras D, et al. (2019). Seeing gravity: gait adaptations to visual and physical inclines- A virtual reality study. Front Neuroscience.

Acknowledgement

This study was supported in part by the Israel Science Foundation (ISF) grant # 1657-16 . We thank Ms. Shani Kimel-Naor and Mr. Yotam Bahat for technical assistance.