KINEMATIC RESPONSES TO GALVANIC STIMULATION OF THE HUMAN VESTIBULAR SYSTEM DURING LOCOMOTION

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INTRODUCTION

Balance is controlled through the integration of vestibular, visual, and proprioceptive senses. The primary aim of this project is to understand the impact of vestibular signals in the maintenance of balance during walking. Galvanic vestibular stimulation (GVS) was used to evoke internal perturbations of the human balance system.

GVS causes perceived head accelerations depending upon the polar orientation of the electrodes. This perception results in postural responses to counteract the perceived acceleration. Typically, GVS is used to cause postural deviations during stance [1,2]. GVS has also been employed to perturb the balance system during gait. Vision has been shown to dominate over the other types of sensory information that dictate the control of movement [3]. Thus, the responses to GVS are present, yet diminished during gait with normal vision [4]. Without vision, subjects involuntarily deviate laterally away from their planned trajectory towards the anodal side [4].

METHODS

Nine healthy young adults (2F, 7M; mean age 25 ± 3.7 years) were screened to be free of neurological and vestibular disorders. Subjects wore tight fitting clothing and standardized rubber-soled shoes as well as a safety harness to protect from ground contact injuries. Before the start of the testing session, subjects were informed that they may or may not experience GVS during any trial.

The skin over the subjects' mastoid processes was abraded (NuPrep$^{\text{TM}}$ gel), cleansed using an alcohol swab, and coated (TENS Clean-Cote® whipe) to decrease skin resistance as well as aid in the adherence of the electrodes. Self-adhering Superior Silver® stimulating electrodes (3.17cm diameter) were fixed over each mastoid process (binaural-bipolar configuration). The galvanic current duration was eleven seconds in total (linear stimulus isolator, model A395R-A, World Precision Instruments, Inc.). Subjects were exposed to two separate five second mock-square waves of alternating polarity (1mA), separated by one second of rest within each GVS trial (Figure 1). Trials with anode towards the subjects' right first (such as displayed in Figure 1) are denoted R^+. Trials with anode towards the subjects' left first are denoted R^-. For any trial where the GVS was applied, only data from the first five seconds of the ±1mA current were analyzed.

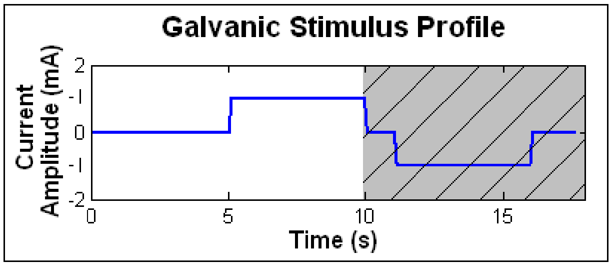

Figure 1: Schematic representation of the galvanic stimulus. The shaded gray area was not analyzed.

Motion capture data (Vicon 612 / M2 camera system) was recorded (120Hz) to collect full-body kinematic responses to GVS. Membrane footswitches were adhered to the sole of the shoes for precise temporal determination of heel contact of both the right and left foot.

A total of twenty-one gait trials (7 conditions, repeatability of 3) were collected using seven types of trials composed of: three GVS conditions (none/R^+/R^-), two eye conditions (open [EO]/closed [EC]), and two GVS trigger conditions (heel contact [HC]/mid-stance [MS]). The trigger condition is relative to the HC of the right foot.

RESULTS AND DISCUSSION

An overall cyclical pattern exists in the ML translation of the sternum and mid-pelvis during gait irrespective of the presence of vision or GVS. Greater maximum ML deviations from control trajectories (EO, no GVS) were observed for the head ($p<0.0001$), thorax ($p<0.0001$), and pelvis ($p<0.0001$) during trials with EC and/or GVS (Figure 2).

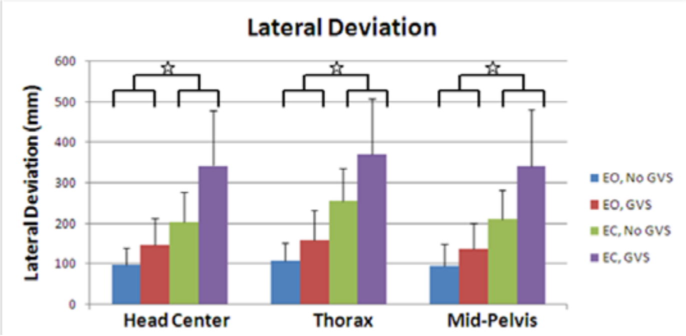

Figure 2: The effect of vision and GVS on lateral deviation (standard deviation displayed) of the head, sternum, and pelvis. The absolute value of the maximum lateral deviation was used to combine GVS R^+ and R^- conditions. Statistical significance denoted with a star.

Furthermore, when examining conditions with EC only, the head ($p<0.02$), sternum ($p<0.01$), and pelvis ($p<0.02$) experienced greater maximum lateral deviations when first exposed to a condition as compared to the second or third exposure to the same condition (Figure 3).

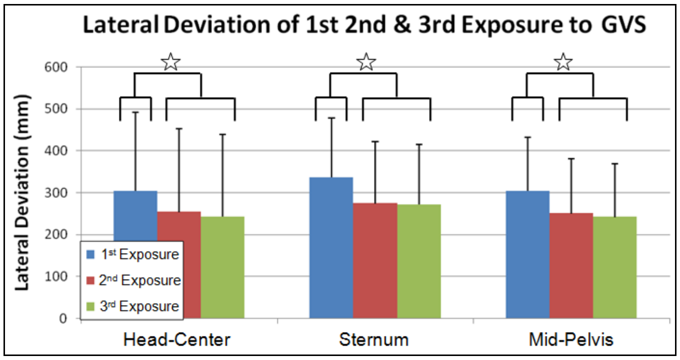

Figure 3: Lateral deviation (standard deviation displayed) due to GVS with EC for the 1st (blue), 2nd (red), and 3rd (green) exposure to GVS collapsed across trigger time and direction. The absolute value of the maximum lateral deviation was used to combine GVS R^+ and R^- conditions. Statistical significance denoted with a star.

The position of the mid-pelvis was obtained at each of the six HCs following the GVS trigger (where GVS activation was at the HC or MS of step 1). GVS significantly altered the position of the mid-pelvis at steps 3 ($p<0.02$) and 4 ($p<0.02$) with EO and at steps 3 ($p<0.01$), 4 ($p<0.01$), 5 ($p<0.01$), and 6 ($p<0.01$) with EC.

Consistent with literature, all subjects deviated towards the anodal side during stimulation. The onset of the response to GVS was observed approximately one stride after GVS trigger with EC. Hlavacka et al. showed that the first whole-body biomechanical signs of a galvanic current during stance are observed approximately one second after the trigger [5]. Our subjects walked at a self-selected pace of approximately 1.2 seconds per stride. Thus, the responses to GVS during stance and gait are temporally consistent, suggesting that the delay seen in GVS responses are due to some neural processing for postural control as opposed to a delay due to the phases of gait.

Current literature states that no “learning” or adaptation exists in response to GVS; no signs of “turning back” towards the original gait target had been observed [4]. Learning was indeed present in this current study. Greater maximum ML deviations were experienced during the first exposure to a specific GVS trial condition. Slip severity, a measure of biomechanical responses to external perturbations, has been shown to lessen after first exposure [6]. It is possible that similar mechanisms adapt to lessen the effect of unexpected internal perturbations, such as GVS, as well as the effects of unexpected external perturbations, such as a slip.

CONCLUSIONS

The aim of this project was to examine the biomechanical responses to GVS during locomotion. Lateral deviations increased during gait without vision. Furthermore, GVS increased the lateral deviation of whole-body movement towards the anodal side during gait with GVS; this effect was exaggerated with EC. Future works will continue to examine the learning effects of GVS, the effects of segmental tilting during gait, and the overall role of the vestibular system during gait.

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