RECOVERY TRAJECTORIES TO PERTURBATIONS DURING LOCOMOTION

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INTRODUCTION

Adapting to microgravity is not the only balance difficulty astronauts face. Major postflight problems include difficulties with standing, walking, turning corners, climbing stairs and other activities that require stability of upright posture and gaze. These difficulties inhibit astronauts’ ability to stand up, bail out, or escape from the vehicle during emergencies and to function effectively when leaving the space/shuttlecraft after flight. Any developed countermeasure must be tested to determine its effect on gait stability, particularly under those conditions that are most troublesome following spaceflight. These include recovering from perturbations during walking, turning corners and climbing stairs. The development of an experimental paradigm that introduces a calibrated disturbance to the foot during the support phase of normal locomotion provides a means for the objective quantification of locomotor response dynamics that are known to be altered in astronauts upon return from exposure to microgravity but for which no current test exists. These responses to perturbations can be characterized by their Recovery Trajectory Duration (RTD). RTD is a measure of the number of paces after the disturbance that it takes for the subject to return to the unperturbed baseline. Returning astronauts whose orientation mechanism has been distorted and patients having vestibulopathies that may well affect their orientation mechanism are expected to have longer RTD’s than healthy normals.

CURRENT STATUS OF RESEARCH

Methods. We investigate locomotor stability by applying a disturbance or perturbation. This approach is an analogue of examining the impulse response often used in the determination of stability of linear and non-linear systems. The perturbation stimulus is generated by a custom-built moveable balance disturber (BALDER) platform, which can be programmed while the motion of their body segments is optically tracked. Four different perturbations and one control case (no perturbation) are delivered to the right foot using a randomized Latin squares design. The perturbations are applied in the X-Y (horizontal) plane at two different amplitudes (5 and 10 cm). Two different directions are used: (1) a 45° angle forward and to the right, and (2) a minus 135° angle rearward and to the left relative to the direction of walking. To ensure that the subject’s left leg is in its swing phase, the onset of perturbation is programmed to occur 200 ms after the detection of the right heel-strike.

Kinematic data are collected using two ganged Optotrak 3020’s (Northern Digital, Waterloo, Ont.). They are placed at a distance of 7.6 m and 13.7 m from the beginning of the walkway respectively, which allows the viewing area of each 3020 to overlap on the BALDER platform itself. This arrangement provides viewing for the arrays over approximately 12 m of walkway, depending on the height of the subject.

Two basic quantities of interest are the mediolateral leg separation and mediolateral torso sway, when sampled at points when the displacements of the right and left legs along the line of march (Y-axis) are equal. Torso sway is analyzed by determining the differential torso sway. That is, we analyze the amount of medio-lateral translation of a marker array placed on the subject's sternum. First, we determine the difference in sternum sway between consecutive steps \(X(n+1) - X(n)\). Then we divide by the differences for the control trials. This is also done on a step by step basis.

Results. The mediolateral displacement of the legs and torso (Fig. 1) show an underlying periodic component that coincides with pacing. Superimposed is a large deviation to the right (downward direction in figure) that occurs after the perturbation, marked by the arrow, is applied. This deviation is followed by a partial recovery toward the original line of march, but typically with a small change in direction we call drift. Less obvious is a transient reduction in the separation distance between the two legs. Our preliminary analysis of these data only considers the responses on a once-per-pace basis that samples the position of both feet and the sternum at the time that one foot is in its support phase and the anterio-posterior position of both feet are equal. We further analyze the difference in response between successive paces in order to eliminate the slight drift mentioned above, but to still capture the dynamics of the response trajectory.
Fig. 1. Mediolateral leg and torso displacements for a 10 cm forward-right perturbation delivered to the right foot during steady locomotion. Arrow shows direction of applied disturbance, while horizontal bar shows its duration. Solid circles show locations of the stance foot at times when both legs have same anteroposterior position. These events are the samples that are used for subsequent analysis.

Fig. 2A shows the averaged difference in response for 12 subjects to a 10 cm right forward perturbation. There is a large right (downward in the figure) response that occurs at the first step after the disturbance. The trajectory subsequently crosses the baseline at the second step to show a slight underdamped response at the third step with a return to, or near, the baseline by the fourth step. The shape and number of paces needed to recover is typical for the other three perturbations. In contrast, the recovery trajectory for a pilot vestibulopathic patient (Fig. 2B) takes several more paces to recover.

Conclusion. The vestibulopathic subject has normal computerized dynamic posturography scores. This would indicate a fairly subtle deficit, and would also suggest that the neuromuscular components of her postural responses are normal. Thus, one conclusion is that this subject has a distortion of her orientation mechanism which does not permit her to recover her trajectory in response to a perturbation as rapidly as healthy subject can recover.

FUTURE PLANS
By comparing the existing data from normals with the data of vestibulopathic subjects taken over the next year, we will develop a quantitative, parametric approach for establishing the limits needed to apply this paradigm for detecting subtle deficits to disturbances of locomotion. We will also coordinate with our JSC counterpart in the continued development of the recovery trajectory approach.