DEVELOPMENT OF AN AUTOMATED TRUNK PERTURBATION SYSTEM

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INTRODUCTION

Trunk instability is a major problem for people with spinal cord injury (SCI), since their lumbar muscles cannot produce sufficient forces to stabilize the lumbar spine. People with SCI often cope with trunk instability by assuming a slumped posture and leaning against the backrests of their chair. When reaching, they use one arm on their lap or thrown over the back of the chair to provide the external forces necessary to keep the trunk from bending forward uncontrollably. Although a significant body of work has been published in the field of sitting balance and posture control, still many fundamental questions remain unanswered.

The Rehabilitation Engineering Laboratory has played a significant part in the development and evaluation of new stimulation neuroprostheses to regain functions such as standing, grasping, and walking. We believe that a closed-loop controlled neuroprostheses would be beneficially to maintain stable sitting posture for individuals in wheelchairs.

In order to develop a neuroprosthesis for sitting balance it was necessary to investigate the neuromuscular systems responsible for trunk stability during quiet sitting. In particular, we were interested in observing systems response in the presence of various types and directions of perturbations. To do that, a unique and automated perturbation system was required.

SYSTEM SPECIFICATIONS

The intent of the perturbation system is to place a subject in a seated position and generate a destabilizing force in any one of a number of directions. To the best of our knowledge a similar system experimental system does not exist to date. The subject's response (movement, muscle activity, and buttock centre-of-pressure) will all be captured simultaneously. Specifically, the requirements are:

- place the individual in a seated position
- provide perturbations in all directions (360 degrees) about the body
- to finely control a tensile perturbation profile (force, velocity, or position)
- maintain a high level of safety (mechanical, software, and electrical systems)

Based on manual perturbation tests on able-bodied individuals, the following system specifications were made:

- 8 actuators positioned in a circle (45 degrees apart) about the subject
- linear actuators capable of :
    - peak force (tension): 600 N
    - peak velocity: 0.5 m/s
    - stroke length: 60 cm

Each of the control profiles (position, velocity, and force) will be precisely modulated through feedback to follow:

- step input
- gaussian (bell)-shaped profiles
- constant velocity (ramp-and-hold)
- randomized perturbation direction

A subject is seated on top of a customized split force-platform placed on top of an elevated box. The subject wears a torso harness attached by cables to 8 linear electromechanical actuators situated in a circle (45 degrees apart) at a distance (roughly 2 m) from the subject. The 8 actuators are capable of independently producing a linear tensile perturbation upon the subject. (Figures 1 and 2).

For each actuator, one can control either perturbation position, velocity, or force to produce tension. A custom, Labview-based (National Instruments) application (under development) allows for a single actuator to be driven while the others are allowed to freely move.

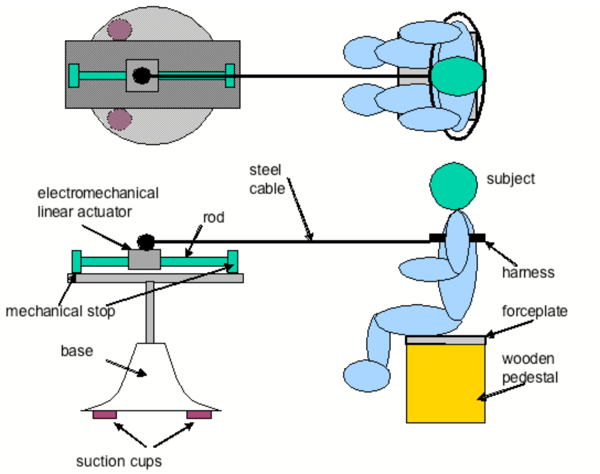

Figure 1: Schematic of Perturbation System

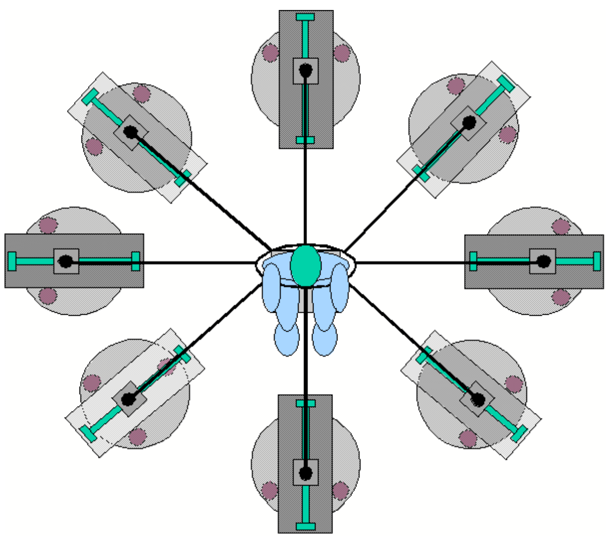

Figure 2: Overhead Layout of Actuators

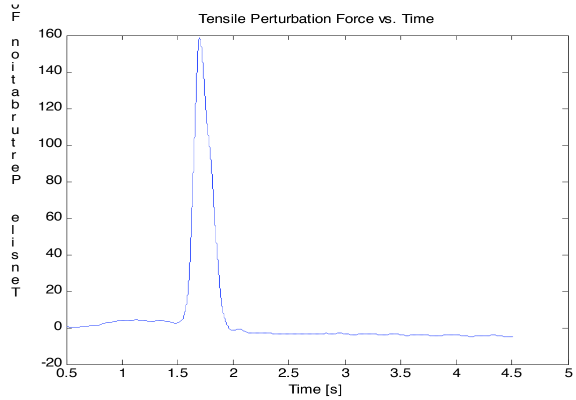

Figure 3: Example of Manual Perturbation Force

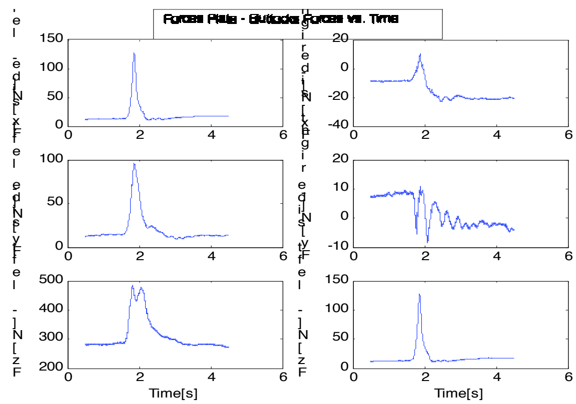

Figure 4: Example of Forceplate Recorded Buttocks Forces

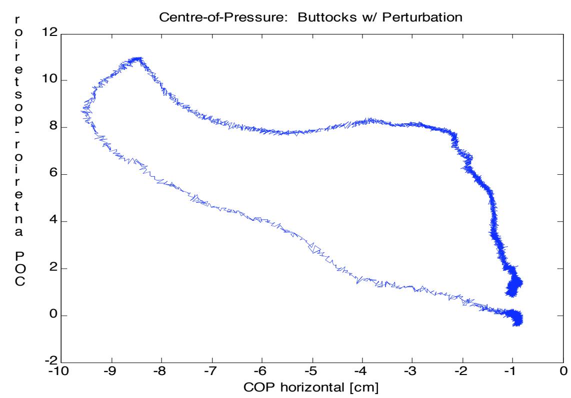

Figure 5: Buttocks Centre of Pressure

DATA RECORDED

A large number of measurements are required to record both the biomechanical and physiological aspects of postural control:

- actuator force / displacement / velocity
- buttock forces / moments / centres-of-pressure
- muscle activity (16-channels electromyography)
- body movement (3D Optotrak motion analysis system; Northern Digital Inc.)

Examples of perturbation force, forceplate recordings and centre-of-pressure from a manual perturbation can be found in Figures 3, 4, and 5 respectively.

PLANNED EXPERIMENTS

The plan for our novel perturbation system is to develop a series of experiments to investigate the primary neuromuscular responses for seated balance and, as well, standing balance.

Prior to prototyping this perturbation system, we have carried out a series of manual perturbation experiments on seated able-bodied subjects to identify the neuromuscular responses to a Gaussian (bell-shaped) perturbation. In these experiments, a human tester generated the force profile by manually pulling the cable. While fairly consistent, manual perturbation suffers from: i) variability of the actuator force, and ii) variability of the subjects response (including anticipation).

Our novel computer-controlled perturbation system, is capable of generating a vector perturbation from in one of eight possible directions, with a randomized delay-time, automated actuator reset, variable tension profile, and automated data acquisition. These characteristics make it a fairly useful tool for obtaining basic postural response.

ACKNOWLEDGEMENTS

The authors would like to thank the Canadian Institutes for Health Research, Toronto Rehabilitation Institute and Bloorview Kid's Rehab for funds making this work possible.

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