

DETECTING A LOSS OF BALANCE IN YOUNG ADULTS PERFORMING A MAXIMAL FORWARD REACH

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INTRODUCTION

The hypothesis was tested that a loss of balance (LOB) is actually a loss of effective control, as evidenced by a control error signal anomaly (CEA: see Methods).

Previous work (Ahmed & Ashton-Miller, 2004) has shown that CEA is detectable and can reliably predict a compensatory reaction in young adults performing a one degree-of-freedom (dof), whole body, planar balancing task. A model-reference adaptive controller and failure-detection algorithm were used to represent central nervous system decision-making based on input and output signals obtained during the task. Our goal is to extend this method to a more complex, challenging three dof task: a maximal forward reach. We therefore tested the hypothesis that a CEA is indeed detectable in 10 healthy young female adults performing a maximal forward reach.

Evidence of successful detection was the initiation of an observable compensatory response (forward step), no earlier than 100 ms after CEA detection and no later than 2s.

METHODS

Ten healthy young women (18-30 yrs) volunteered as subjects. Subjects were asked to reach forward as far as they could with both hands towards a circular target (Fig.1). They were allowed to lift both heels but not to bend their knees as they performed the task.

The target was randomly positioned at varying percentages of their maximum reach distance (100, 105, 110, 115,120, and

125%). They were instructed to attempt to reach the target and hold the position for 10s. Sufficient reach trials were recorded to accumulate 10 trials, each with an involuntary step.

Body segment orientation and location in three-dimensional space was measured at 100 Hz using infrared light-emitting diodes (LED) markers and an Optotrak 3020 system. Nine markers were placed on bony landmarks up the right-side of the body, obtaining the kinematics of the foot, shank, thigh, torso and head (Fig. 1). Subjects stood with each foot on a separate AMTI six-channel force-plate. Three dimensional ground reaction forces and moments were recorded at a sampling frequency of 100 Hz. The task was modeled as a triple inverted pendulum, consisting of the FOOT, shank-thigh (LEG), and head-arms-torso (HAT) segments. Joint torques (T_{hip} , T_{ankle} , T_{toe}) were obtained through inverse dynamics. Height, weight, and body segment lengths were measured for each subject.

The joint torques represented the system inputs. Angular acceleration of the FOOT

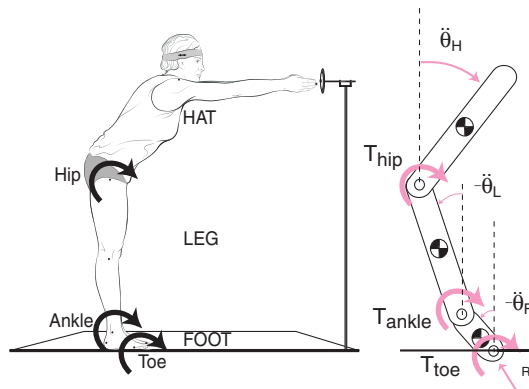


Figure 1: Subject beginning forward reach (left). Triple inverted pendulum model of human reaching (right)

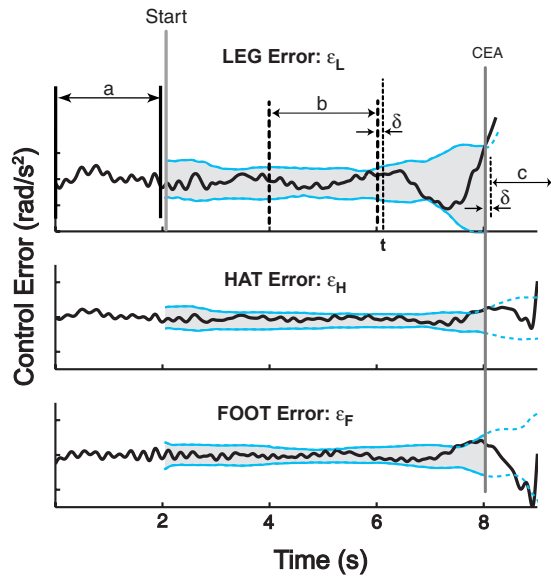


Figure 2: Schematic of three control error signals: ε_L , ε_H , ε_F (black) and $\pm 3\Sigma$ thresholds (shaded). 3Σ algorithm is described on ε_L (top).

($\ddot{\theta}_F$), LEG ($\ddot{\theta}_L$), and HAT ($\ddot{\theta}_H$) constituted the three dof freedom system outputs. Three control error signals were formed, ε_F , ε_L , and ε_H , defined as the residuals generated when each of the actual system outputs is compared to the corresponding predicted output of a nominal forward internal model using the given torque inputs. CEA was detected once an error signal first crossed a threshold level set at three standard deviations (3Σ) beyond the mean value in a 2-second-wide moving window, **b**, which trailed the current time instant, **t**, by 100 ms (**δ**). (Fig 2: The threshold calculation begins at ‘Start’, initially using baseline data in window **a**.) LOB was confirmed by the occurrence of a step within 2 s of and no earlier than 100 ms from CEA detection (window **c**). The occurrence of a step was defined as a compensatory response, and evidence of CEA perception.

RESULTS AND DISCUSSION

In 83.6% of 98 trials a CEA was detected when ε_L crossed either the upper or lower 3Σ threshold. Monitoring ε_H or ε_F provided similar reliability ($\chi^2: p > 0.1$). The optimal threshold level was 2.6Σ , with 85.4%

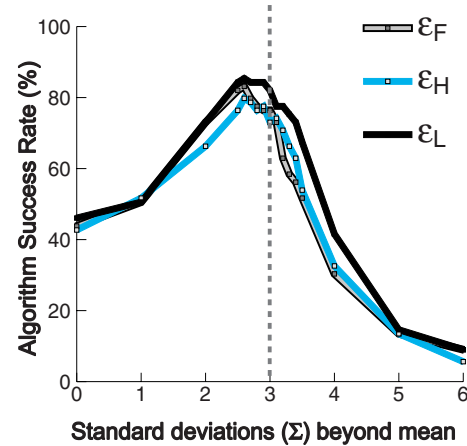


Figure 3: Threshold sensitivity analysis for each of the three control error signals

reliability, slightly greater than the 83.6% obtained with 3Σ (Fig 3). Monitoring both thresholds on ε_L provided a 72.4% success rate ($p > 0.05$). Detection algorithms based on absolute velocity or position thresholds (maintaining the center of mass, COM, within the base of support, BOS) were significantly less reliable in detecting LOB: 56% and 29%, respectively ($p < 0.005$). It is noteworthy that CEA detection does not require calculation of the COM kinematics or the BOS. There is also no need for an absolute position reference, or maximum strength estimates.

SUMMARY

The results support the hypothesis that a LOB is a loss of effective control. The 3Σ algorithm detected a CEA and predicted the need for a compensatory response using this multi-input, multi-output model of an activity of daily living-type task.

REFERENCES

Ahmed, A.A., Ashton-Miller, J.A. (2004) *Gait & Posture, epub/in press.*

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