AN ANALYSIS OF LOSSES OF BALANCE DURING TANDEM STANCE ON A NARROW BEAM

[1]Alaa A. Ahmed and [1,2]James A. Ashton-Miller
Biomechanics Research Laboratory
Departments of [1]Biomedical and [2]Mechanical Engineering
University of Michigan, Ann Arbor, MI, USA; email: aaahmed@umich.edu

INTRODUCTION

Most falls are preceded by a loss of balance. Given that there are few mechanistic explanations for 'loss of balance', we have hypothesized it to be a loss of effective control, detectable as a control error anomaly (CEA). We have used a model-reference adaptive controller to represent the central nervous system along with a failure detection algorithm to mimic how it makes decisions based on input and output signals obtained during the task [1,2]. In this paper we examine the ability of this method to detect a loss of balance in a three-dimensional, multi-degree of freedom (dof) balancing task: tandem stance on a narrow beam. We hypothesize that a control error anomaly will predict the occurrence of a compensatory step off the beam at least 100 ms, and no more than 2 s, later.

METHODS

Ten young (18-30 yrs) female subjects were tested. Subjects were asked to stand in tandem (heel-to-toe) stance on a narrow beam (2.5 cm wide) for a maximum of 60 seconds (Fig 1). Each subject performed a minimum of 15 trials.

The human was modeled using eight three-dimensional rigid body segments: trunk, pelvis, right and left feet, calves, and thighs. Twenty-eight optoelectronic markers recorded the segment kinematics; ground reaction forces and torques were also recorded from two force plates to which the beam was bolted. Joint torques were calculated using inverse dynamics.

We considered the joint torques to represent the system inputs, while the segment accelerations represent the 8x3 system outputs in the three orthogonal planes. The corresponding control error signals were 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 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 1: 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.

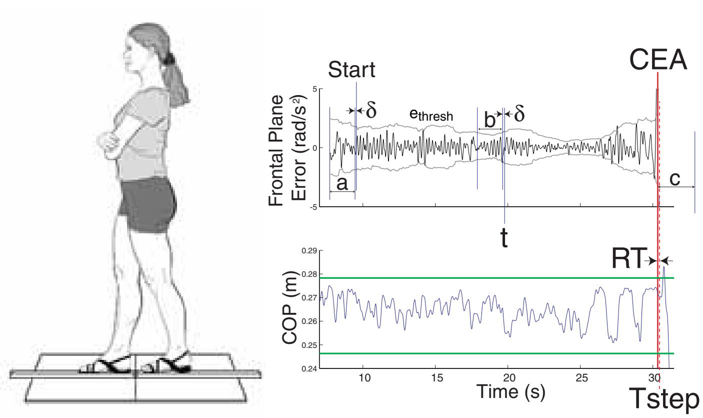

Figure 1 *Left: Subject in tandem stance. Right (top): Algorithm schematic of one of the 22 control error signals analyzed and (bottom) center-of-pressure (COP) in the frontal plane with time of step initiation, Tstep, marked by a vertical dotted line. The horizontal lines (bottom figure) delineate the beam outline.*

RESULTS AND DISCUSSION

This is the first test of the CEA hypothesis in a 3D multi-dof balancing task. The 3Σ algorithm correctly detected a loss of balance in 71.6% of 148 trials by either predicting the step off the beam when one occurred, or by not predicting a step when one did not occur. In this case, the first of the 8 segment control error signals in the frontal plane to reach 3Σ was used to detect CEA. Similar results were obtained when monitoring control error in either the sagittal (64.9%) or transverse plane (64.2%). Control error within a given plane was a better step-predictor than individual segment control error ($p<0.05$, Table 1), and segments performed equally ($p>0.05$). Importantly, kinematic signals such as segment and whole-body center of mass (COM) position, velocity and acceleration were significantly less reliable than CEA ($p<0.01$, Table 1). The optimal threshold level for CEA detection was 3Σ, supporting earlier results in sagittally-symmetric seated [1] and standing reach [2] balance tasks. In contrast to kinematic measures, CEA emphasizes the importance of the control input, and the input/output relationship in the perception of a loss of balance.

CONCLUSIONS

The results support the definition of a loss of balance as a loss of effective control. Control error is a more reliable predictor of a compensatory response than body kinematics in this three-dimensional, multi-input, multi-output balancing task.

REFERENCES

1. Ahmed AA, Ashton-Miller JA, *Gait Posture* **19**, 252-262, 2004.
2. Ahmed AA, Ashton-Miller JA, *Proceedings of ASB XVIII*, Portland, OR, 2004.

Table 1: Success Rate of Various Algorithm Detection Schemes (χ^2 probability relative to Within-Plane Error, * $p<0.05$, ** $p<0.01$)

	Within-Plane Error	Segment Error	COM Acceleration	COM Velocity	COM Position
Success Rate (%)	71.6	60.8*	31.8**	56.1**	38.5**