STABILOGRAM DIFFUSION ANALYSIS APPLIED TO DYNAMIC STABILITY: ONE-LEGGED LANDING FROM A SHORT HOP

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INTRODUCTION

Dynamic stability describes the process of transitioning from movement to a quiet, standing posture. Time-to-stability (TTS), based on the diminishing fluctuations in ground reaction forces and center-of-pressure (COP) trajectories, is often used to assess this transition [1]. Static postural stability is often assessed by analyzing the displacement of the COP while a person stands quietly on a force platform [2]. These approaches result in gross indicators of overall stability, but are criticized because of the limited physiological meaning that can be derived from the dependent variables. Typically, protocols that examine responses to perturbations, changes to sensory systems (e.g., vision), and differences in injury status are used in conjunction with the aforementioned approaches.

Collins and DeLuca [3] introduced a method of assessing stabilograms based on techniques from statistical mechanics. Their intent was to introduce a method that resulted in more physiologically meaningful results. Their stabilogram-diffusion analysis (SDA) modeled quiet standing as a system of coupled, correlated random walks [3]. The mean squared displacement between COP coordinates and their respective time interval are plotted (see Figure 1) and a critical point is identified where the slope changes from very steep to much shallower. The resulting two regions of the stabilogram-diffusion plot (short-term and long-term) have been suggested to be associated with postural control changes from a primarily open-loop process to a closed-loop process. The purpose of the present investigation was to apply this SDA to a dynamic stability protocol, where a person hops, lands on one foot, and gains stability (as in TTS studies). It is intended that further insights will be gained into how individuals become stable at the end of a dynamic task.

METHODS

Twenty healthy, recreationally active men (n=9) and women (n=11) volunteered for this study (age = 28 ± 4 yrs, body mass = 73.3 ± 21.5 kg, body height = 173.4 cm ± 10.5 cm). Participants were asked to complete a hopping task onto an AMTI force platform (barefoot, landing with dominant leg). After taking two steps, individuals took a forward hop from 100% of their leg length. Three trials were collected and analyzed for each person.

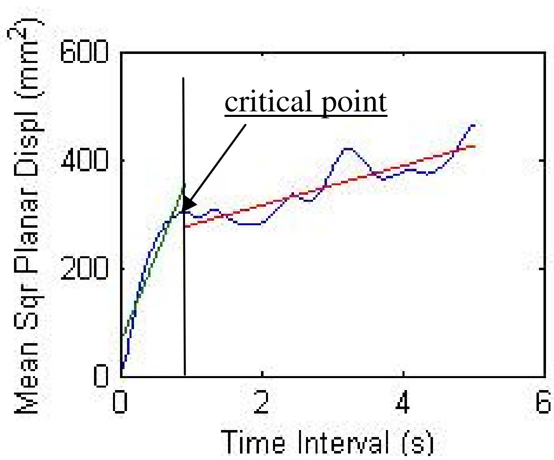

Figure 1: A representative resultant, planar stabilogram-diffusion plot. The vertical line goes through the critical point, which splits the plot into short-term and long-term regions. Least squares linear fits are shown in each region.

Ground reaction force data were collected at 100 Hz for 10 s after landing. COP coordinates were calculated and a SDA was applied to the COP-time series following the procedures of Collins and DeLuca [3]. From the mean square displacement-time interval plots, a critical value was determined that identified the short-term and long-term regions.

Diffusion coefficients (D_S, D_L) were calculated as one-half the slope of each least-squares linear fit to each region of the plot (see Figure 1). Similarly, scaling coefficients (H_S, H_L) were calculated from log-log plots of these curves [3]. These coefficients, values of the critical points, and R^2 values for line fits were compared to static stability results.

RESULTS AND DISCUSSION

Coefficients from the SDA assessment for dynamic stability in the present study were greater than values reported for static tests (see Table 1). Data from two sources [3, 4] are also shown in Table 1 for comparison. Collins and DeLuca [3] reported data for two separate groups, which differed in how many trials each participant attempted.

Table 1: Mean diffusion coefficients (D, $mm^2 \cdot s^{-1}$) and scaling exponents (H) for the short- (S) and long-term (L) regions of the SDA.

	D_S	D_L	H_S	H_L
Means	450.59	36.86	0.49	0.13
SDs	(181.66)	(23.64)	(0.04)	(0.08)
Means [3a]	6.74	1.76	0.76	0.28
Means [3b]	11.21	3.05	0.76	0.34
Means [4]	11.00	2.10	0.80	0.24

Note: Mean values from [3] are from two different groups (a, b) and mean values from [4] are from 30-s trials (they also analyzed data after 60 and 90 s).

The diffusion coefficients and scaling exponents from the linear fitted lines resulted in mean R^2 values greater than 0.95, except for D_L, which had a large range of values and a mean of 0.54.

In the present study, the mean critical point coordinates were (0.72 s, 587 mm^2) as compared to (1.04 s, 13 mm^2) from Collins and DeLuca [3] and (1.02 s, 16 mm^2) from Doyle et al. [4]. For all trials in the present study, this critical point was clearly identified, which was not the case in a previous study [3]. The critical time interval has been suggested to be indicative of a switch from open loop to closed loop control. Based on the previous suggestions, the critical time interval identified in the present study suggests that a switch between control processes took place at shorter time intervals in our dynamic task. This may be due to the less stable condition (one-legged standing after landing) compared to static, two-legged conditions or possibly the difference between the dynamic and static tasks themselves.

In addition, the values of the mean square displacement for the critical point and the diffusion coefficients are greater than values for static stability [3, 4]. Because one-legged standing after a short hop results in much greater movement of the COP during stabilization, it is not surprising that mean square displacements calculated across longer and longer time intervals would be greater.

In the present study, the mean short-term scaling exponent (H_S), resulted in a value of 0.49, with values from all 20 participants ranging from 0.40 to 0.54. This is a fundamental departure from the two-legged static SDA, where H_S was greater than 0.5 in all subjects [3]. Classical Brownian motion exists when H = 0.5, thus in the present study, COP movements over short-term intervals are purely random. The extremely high values of D_S support this interpretation. After the critical point, the mean long-term scaling exponent (H_L) decreased to 0.13, which describes nonrandom COP movements over longer time intervals. Taken together, these results suggest control for this stabilization task changes from a non-regulated process to a more tightly controlled one (e.g., closed loop) [3].

CONCLUSIONS

Compared to two-legged static stability, SDA for one-legged landings from a hop resulted in random COP motion over short-term intervals and a much clearer transition to tighter postural control.

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