Modeling and Analysis of Posturographic Data Using Markov Chains

Pilwon Hur, K. Alex Shorter, and Elizabeth T. Hsiao-Wecksler

Department of Mechanical Science and Engineering
University of Illinois at Urbana-Champaign, Urbana, IL, USA
E-mail: ethw@illinois.edu Web: www.mechse.illinois.edu/research/ethw/

Posturographic data collected during quiet stance using force plates is widely used to assess postural stability [1]. Center of pressure (COP), the location of the resultant reaction force underneath the subject's feet, is a commonly used experimental variable for several types of analyses. Traditionally, COP data has been analyzed using measures that describe the shape or speed of the trajectory [1]. However, these parameters do not provide insight into the physiological system as a whole, and have been shown to have questionable reliability [2]. Collins and DeLuca addressed this problem by modeling the COP trajectory as a one or two dimensional random walk, and created Stabilogram Diffusion Analysis (SDA, a stochastic analysis) to characterize short term (open loop) and long term (closed loop) postural control strategies [3]. While SDA characterizes underlying behavior in the data set, the characterization of the long term behavior can be improved. The goal of this work was to utilize a Markov chain model of the COP data to provide new insight into the long term behavior of quiet standing data.

In this study, we consider the COP as the output that results from the stabilizing mechanism of the human postural control system. This dynamical system is a stochastic process and does not have closed form equations [3]. As a result, a Markov chain with a finite state space was used to describe the system's dynamic evolution. States were defined as set distances away from a center point (i.e., the average value of the COP for the entire trial). The transition probability from one state to another was described with a probability transition matrix (**P**) [4]. In our case, **P** was defined as the probability that the current state (a given distance from the mean COP value to the current COP value) will evolve to another state. The invariant density of the Markov chain was found using the probability transition matrix, **P.** Invariant density is the distribution where the Markov chain converges regardless of the system's initial conditions and describes the asymptotic behavior of the system [4]. Invariant density describes the probability of finding the COP at any given distance away from the center. The peak value of the invariant density can be interpreted physically as the distance within which the COP is most likely to be found. Spectral decomposition was used to compute the approximate time for the COP to reach its invariant density.

Using the derived invariant density, four parameters that describe the long term behavior of the system were defined: peak probability (P_{peak}), distance from center to peak probability (D_{peak}), distance to 95% cumulative probability (D_{95}), and time to reach Invariant Density (T_{inv}). Quiet stance trials were conducted with three different age groups: young adult (YA), middle-aged adult (MA), and old adult (OA). The results showed P_{peak} decreased as age increased, while D_{peak}, D_{95}, and T_{inv} increased as age increased. YA and MA age groups were statistically different from OA at two parameters ($p<0.05$): P_{peak} ($p=0.001$) and D_{95} ($p<0.001$). Additionally, a nearly significant difference was present in T_{inv} ($p=0.07$). Therefore, invariant density analysis (IDA) can be used as a tool to characterize posturographic data.

References

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