STATE OF THE SCIENCE IN POSTURAL STABILITY RESEARCH

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ABSTRACT

Postural stability is an emerging area of research. Recently there has been much research investigating the viability, sensitivity, and reliability of metrics of postural stability but among these there has been little justification and agreement. The aim of this paper is to briefly highlight mechanics of postural stability, common study approaches to quantify postural stability, the limitation of these study approaches, and finally propose some possible direction to better understand postural stability. Center of pressure and its associated derivatives, the total body center of mass, and plantar pressure distribution are the primary metrics used to quantify postural stability. There is no consensus in the literature that any of these parameters can predict postural stability. It was determined that the state of the science in postural stability studies is primarily restricted to measurements in a single plane using a force platform. It was also determined that variability in measured data, lack of sensitivity in data, and lack of a multi-factorial approach capable of capturing many parameters influencing postural stability has all contributed to the confusion and subsequent lack of agreement in the literature. To address many of these challenges it is recommended that the role of optimization, the use of Microelectromechanical inertial accelerometers, and the application of more robust solution techniques to solve the inverted pendulum model be deeply explored.

INTRODUCTION

The primary purposes of determining postural stability during a clinical balance assessment are: 1) to identify whether or not a balance problem exists in order to predict risk of fall or to determine whether treatment is needed or has been effective; and, 2) to determine the underlying cause of the balance problem in order to manage or treat it effectively [1]. Previous studies have highlighted a connection between postural stability and the ability to avoid falls [2]. Falling among the elderly is high, whereby among the elderly population, 70% of the injuries caused by accidents are related to falls [3] and aging seems to increase the severity and amount of injuries [4]. Being able to better understand postural stability can facilitate the development of training programs, exercise regimens, and mechanical interventions to prevent falls. The objective of this paper is to outline the mechanics of postural stability, highlight existing approaches to quantify postural stability, outline the limitations of existing study approaches, and finally present some new ideas to better tackle the challenges confounding our understanding in postural stability.

MECHANICS OF THE PROBLEM

The human body has a small base and a high center of gravity and as a result constantly requires the capabilities of postural control system to maintain balance. Postural stability is defined as the ability to maintain or control the center of mass (COM) in relation to the base of support (BOS) to prevent falls and complete desired movements [5]. Balancing is the process by which postural stability is maintained. The postural control system requires sensory inputs from the visual, somatosensory, and vestibular receptors in combination with the central nervous system to adjust the activation of muscles so as to maintain postural stability. Postural instability may occur as a result of decreased sensory input (sensory system), slowing of motor response (motor system) and weakness of bones and joint system (biomechanical system). The characteristics of center of pressure (COP), COM, and plantar pressure distribution have been used to quantify postural stability. To date the most widely used approach for postural stability research is to assume the body as a rigid inverted pendulum pivoting about the ankle joint. This model was pioneered by Winter [6] and can be used to study movement in a single plane. This model is only applicable to body movements about the ankle joint during quiet standing yielding the following equation:

$$COP - COM = k\ddot{x} \qquad (1)$$

where $k = \frac{I}{Wh}$. Here $\ddot{x}$ is the horizontal acceleration of the body COM, I is the moment of inertia of the body, W is the weight of the body, and h is the vertical distance from the body COM to ankle joint. As gleaned from equation 1, the combined interpretation of COP and COM displacement may provide better insight into the assessment of balance than COP and COM quantified separately. The disadvantages of this model is it lumps many body segments into one, the effect of hand or trunk movement to postural stability cannot be studied, and it requires the use of body segment parameters mostly commonly determined from cadaver based regression equations.

COMMON POSTURAL STABILITY STUDY APPROACHES AND THEIR LIMITATIONS

The force platform is the primary device used to measure COP. COP can also be determined from plantar pressure devices such as a Mat Scan Clinical System (Tekscan Inc., Boston, USA) or a Force Sensing Application (FSA) insole (Vista Medical Ltd, Winnipeg, MB, Canada). The trajectory of the total body COM is also commonly employed in studies on human posture and balance primarily through the use of video based motion analysis system [1].

Application of Force Platform to Postural Stability Measurement

The force platform is used to measure the forces and moments recorded via sensors mounted at various locations of the force plate. A point can then be calculated using these values which indicate the location of the resultant ground reaction force (GRF). This point is called the COP. The movement in COP is then used to quantify postural stability. Various statistical parameters are then derived from the COP and used by many researchers to assess sensitivity and reliability of these parameters to discriminate subtle differences in postural stability so as to detect effects of changes in afferent sensory signal, diseases, age, weight and height on postural stability.

Typically the test procedure for postural stability studies entails instructing subjects to stand quietly on the force platform with arms hanging freely at the sides. The subject is then instructed to look straight ahead with head erect while maintaining there balance for period of approximately 30s or longer. A compromise needs to be made between trial duration, variability in data, and patient's ability to maintain posture for long duration. To ensure identical BOS within trials, tracings are usually taken of the foot placement on force platform.

The application of the force platform study approach to postural stability is limited by the lack of pliability and portability. In addition, the cost of a force platform may also be a barrier to some research groups. As well, a force platform does not capture the many uneven surfaces, slopes, stairs, as well as, smooth and rough surfaces that are regularly encountered outdoors in our everyday life and that constantly challenge our balance.

Application of Motion Analysis to Postural Stability measurement

Studies using motion analysis were primarily interested in determining the total body COM via a video based motion analysis system. The total body COM trajectory provides a measure of stability. To quantify postural stability using motion analysis typically a certain number of infrared emitting diode (IRED) markers are placed on various body segments. These markers are placed on the end points of each body segment and the coordinates are captured in time and space via some hardware A/D converter and software interface. A system such as the OPTOTRAK sensor system (Northern digital Inc., Waterloo, Canada) records marker displacement for movement performed by subject. An approach called the segment kinematic method is then employed and entails determining the body COM location by taking the weighted average of all body segments center of mass location over time. A biomechanical model is typically used to visualize the subject movement and characteristics.

Studies that utilize motion analysis to quantify postural stability are few due to the high equipment cost, the large amount of data involved and the time required processing the data, and the relative ease of use of force platform equipment. The setting up of the markers for motion capture can also be burdensome and time consuming. Occlusion of markers, as well as, skin artifacts also poses some challenges to the use of motion analysis for postural stability research. Finally the accuracy of this study approach is dependent on accurate determination of body segment parameters.

Application of Plantar Pressure distribution technique to Postural Stability measurement

Plantar pressure measuring devices are used primarily because of low cost and relative ease of use in a clinical setting. Studies by Tanaka and colleagues [7, 8] assessed the effects of foot pressure contribution on standing balance and its association with aging. Plantar pressure measuring devices includes, but not limited to, the F-Scan Tactile Sensor System (Tekscan Inc., Boston, USA), Mat Scan Clinical System (Tekscan Inc., Boston, USA) and Force sensing application (FSA) insole (Vista Medical Ltd, Winnipeg, MB, Canada). The use of these devices to assess postural stability follows the exact procedures as that when using a force platform.

Pressure saturation is a major limitation of plantar pressure techniques [9]. The calibration procedure of some plantar pressure systems is cumbersome and lengthy. For example, for the FSA system, if the subject sways under the FSA's threshold of 0.25cm, the system will record a constant position [9].

RECOMMENDATIONS

A multi-factorial approach that can concurrently capture the many parameters influencing postural stability can address some of the challenges with existing study approaches. This approach may utilize optimization to search and locate the many parameters influencing postural stability. Optimization may also be used to determine analytical model parameters that yield reasonable results when compared to experimental data. Moreover, a more robust approach to solve the two segment inverted pendulum model such as work energy theorem may provide improved results when compared to existing approach used by Winter [6]. A 3D bilateral multi-segment model is need which can provide significant insights since existing models can only handle single plane motion. Finally, attaching an accelerometer at the approximate height of body center of gravity has provided a quick and easy way to determining total body center of gravity [10]. Hence, the use of Microelectromechanical systems (MEMS) inertial sensor that measures velocity and acceleration when placed on the head, hip, or spine may provide a clinic friendly, simple, portable and cost effective way to quantify postural stability.

DISCUSSION

The equipment used to measure postural stability differs widely and different parameters are measured and analyzed for each approach. This makes it difficult to compare studies in the literature with each other. One study [11] concluded that it is important in research and clinical situations to compare only trials of the same duration using the same outcome parameter. However, very few studies use the same test duration or identical metrics. Variability also stems from the experimental procedure adapted as well as the inherent variabilities of the biological event being measured. For example, standing still to conduct postural stability studies for long periods for an elderly person is difficult due to fatigue. Fatigue may result in variability in data obtained [9, 11].

The lack of consensus in postural stability studies suggest that more research is needed to develop standardization in postural stability study approaches. One major challenge has been to develop unified approach that can discriminate factors contributing to postural instability. The importance of being able to repeatedly reproduce postural stability results with a specific test protocol has also been an endeavor for researchers.

Factors such as subjects' past experiences, there current attention to a task, the actual task being undertaken, and the environment in which the task is being done – all of which the investigator has no control - may influence postural stability [12, 13]. In addition, one study argues that the substantial heterogeneity in postural stability data especially among the elderly could be linked to individual characteristics and lifestyles [14].

CONCLUSIONS

Despite extensive efforts to standardize parameters such as test protocol, test duration, and choice of metrics to reliably quantify postural stability, the time varying nature of the COP makes this task challenging. What is required is a parameter or a method of representing the COP movements in a manner that would yield maximum discrimination between age groups, body types, situations, and diseases known to influence postural stability. Only then can we be able to detect with some certainty individuals who are at high risk of falling. No one technique can evaluate all aspects of postural stability. The type of technique used by the clinician depends on the purpose of the assessment, specific movement, patient studied, type of balance disorder, and the resources available. Consideration should be given to all these factors in future studies aimed at developing postural stability tools for clinical application. Employing optimization, MEMS accelerometers, and new solution techniques to solve the inverted pendulum model may help mitigate the confusion stemming from postural stability research.

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