

No Space? No Problem. Accessible Balance Control Using VR Player Movement*

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Abstract— Balance assessments are a common method of measuring vestibular and proprioceptive function as well as lower-body strength. Aside from observational clinician analysis of balance exercises, more detailed and conclusive assessments are typically performed using large, nonmobile, and expensive immersive systems. The purpose of this project is to replace existing balance testing equipment and provide an alterable environment for clinical postural control evaluation to enable development of personalized physical rehabilitation methods. To assess and train postural control, balance, and strength, this project incorporated real-time center of pressure data of a user on an on-floor force plate as the user completed a unique balance assessment in a Virtual Reality (VR) environment. Leaning or other movements altering the center of pressure location correspondingly caused movement through the VR environment. The VR environment was designed to assist ankle injury rehabilitation and included tasks to evaluate and compare mobility of the ankles. Quantitative measurements of 2-dimensional range of motion were coded to be recorded and coupled with clinician observational analysis for physical therapy applications. Lag between the force plate and VR device was minimal to prevent motion-sickness, and users could navigate through the VR environment, including tight areas, using planted sway movements with ease. This project developed novel physical rehabilitation methods using quantitative postural control analysis and can be further expanded upon to improve numerous physiological or vestibular conditions.

I. INTRODUCTION

Postural control analysis is used in modern clinical settings to assess coordination, proprioception, vestibular system function, and neurological and physiological effects of injuries and brain trauma [1], [2]. Postural control has been assessed using sophisticated equipment, such as the NeuroCom™ Balance Master System, as well as with clinician observation of balance in baseline balance testing [1]–[3]. A limitation of such specialized methods is that the equipment, including the NeuroCom™ Balance Master

system, are unportable, expensive, and rely on observational analysis to measure balance performance [2].

Virtual reality (VR) encompasses technological systems that provide manipulated viewing spaces for a user, generally using a headset equipped with a screen that follows the head motions of the user. VR is currently used widely for entertainment but has also been applied to rehabilitation strategies such as phantom limb pain treatment and emotional therapy [4], [5]. Advantages of VR applications of postural control studies includes greater portability; lower financial expense; connectivity to quantitative digital measuring systems; and greater environmental control for providing individualized and interactive scenarios and assessing a variety of clinical applications.

In related VR studies, physiological markers have been used in collaboration with VR environments including the tracking of heart rate (HR), electrodermal activity (EDA), electrocardiogram (ECG), electromyography (EMG), and others [6]–[10]. Such research has targeted uses such as quantifying anxiety and cybersickness levels in VR experiences as well as physiological function of muscles and limbs during VR tasks [7]–[9], [11]. Another popular use of VR in the clinical field is with phantom limb therapy where immersive or augmented strategies are used to reduce pain attributable to complex neural dysfunction long after the loss of a limb [4]. This application demonstrates that VR is a useful tool in physical therapy and allows unique and individualized circumstances to be realistically simulated. Another notable study included a comparison between motor skill rehabilitation outcomes with and without the use of VR [10]. In this study, Santos Pessoa De Melo et al. determined that patient performance was significantly improved with the use of VR, possibly due to the quality of immersion within VR environments which may improve focus, interest, and motivation [10]. This demonstrates that VR may improve physical therapy methods by influencing patient attention and focused activity. This considered, the utilization of virtual and augmented reality for physiological evaluation has been a rising trend, but applications of VR and force plates

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have been examined to a lesser extent in current literature. The primary goal of this project is to extend on these findings and develop applications that use VR in parallel with force plate data.

Force plate data have been used to assess postural control by measuring variables such as the displacement curve area and the velocity, standard deviation and displacement frequency of the center of pressure (CoP) [12], [13]. The quantitative CoP data allow force plate posturography to effectively analyze both static and dynamic postural control [13]. Methods for postural control evaluation and rehabilitation practice can be advanced using quantitative data gathered through time-dependent kinetic measurements of a force plate coupled with controlled VR simulated environments, allowing reduced observational variation and clinical error. The use of a force plate allows for quantitative data collection of user movement and reduces both space requirements and the risk of collisions with an external environment in the VR space.

The purpose of this project is to replace existing unportable and expensive balance testing equipment, provide an alterable environment for clinical postural control evaluation, and initiate novel physical rehabilitation methods.

II. METHODOLOGY

A. Materials

A portable Bertec™ force plate (MN: FP4060-05-PT) was used to measure total downward force and CoP on a 2-dimensional plane [17]. This plate uses precision-engineered, strain gauge load transducers that precisely measure six components: three orthogonal forces and the moments about each axis [17]. The CoP coordinates are then computed as moments divided by forces (ex. M_x/F_y). The plate outputs the six components along with the time-dependent CoP location in the x-y plane [17].

An illustration of the anterior-posterior force plate output integration to VR maneuvering and movement is shown in Fig. 1. This one-dimensional illustration was applicable in two dimensions, resulting in translational movement in the x-y plane in the virtual environment based on CoP movements.

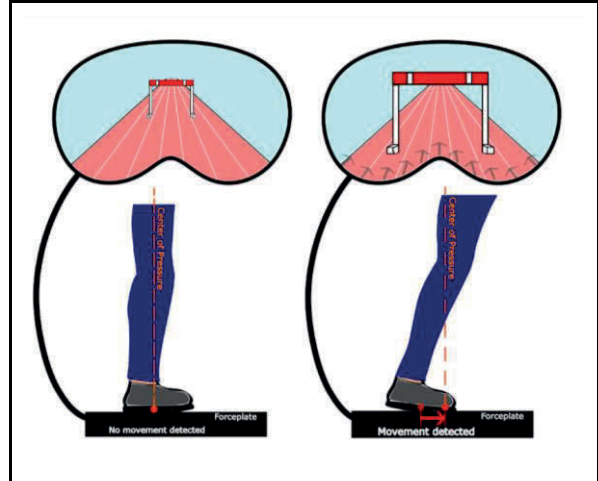


Fig. 1 An illustration of movement on a force plate initiating VR movement.

The VR headset used in this study was an Oculus™ Rift CV1. Although this headset has a slightly lower resolution compared to other headsets, such as the Quest 2, it runs faster and has a better Personal Computer connected Virtual Reality (PCVR) performance. PCVR refers to the apps that run on a PC and their connection to the VR headset. Unity, a game design platform used in this study, has built in support for many different VR devices and therefore it is possible to utilize other commercially available VR hardware.

B. VR Environments

To produce interactive VR situations and measure motion and balance control, two VR environments were created using Unity™. The first environment involved a lateral maneuvering activity with virtual pylon cones. The cones were placed in a line and the user was tasked to weave between the cones while moving forward to get to the finish line. An even number of obstacles was maintained to ensure each side was trained and measured equally. Two levels were created; first included a line of single pylons, followed by a second level with pylons grouped laterally in groups of two. This served as a bilateral motion control evaluation to determine disparities between the left and right lower body regions. The game environments in Unity™ are shown in Fig. 2.

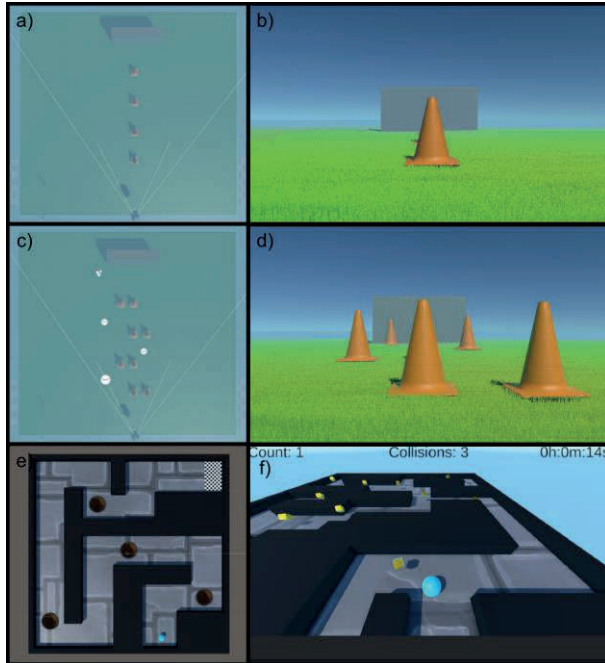


Fig. 2.a An aerial view of the cone maneuvering task environment Level 1 in Unity™.

Fig. 2.b The player view of the cone maneuvering task environment Level 1 in Unity™.

Fig. 2.c An aerial view of the cone maneuvering task environment Level 2 in Unity™.

Fig. 2.d The player view of the cone maneuvering task environment Level 2 in Unity™.

Fig. 2.e An aerial view of the stability task maze environment in Unity™.

Fig. 2.f The player view of the collection task maze environment in Unity™.

The second environment was in the form of two mazes which included a time-dependent measurement of performance. This task, as opposed to the cone maneuvering task, was used to evaluate the efficiency of balance control and error correction using a timer and collision counter. Performance in the first maze task was measured using time to collect all the gold pieces and counting the number of collisions with the wall. Faster completion times and fewer wall collisions indicate better performance on this task.

In the second maze task, the user was instructed to solve the maze with minimal collisions, but also to stand still for a period of time on each shield on the floor of the maze. During the quiet stance periods, CoP data were measured and can be used for sway analysis. Less sway (e.g. velocity, area) during the quiet stance periods and fewer wall collisions during the entire task indicate improved performance. The maze environments in Unity™ are shown in Fig. 2.

C. Study Procedure

During testing, a PI stood on the force plate and secured the Oculus™ headset. Using a PC running on Windows 10, the cone or maze game environment was selected. The task was then attempted by the user, maneuvering through the VR environment by leaning in a 360° range. When the user leaned in a direction, their view traveled translationally in that direction as well. Following the completion of the VR task, their total CoP path over time in two dimensions was recorded as a force plate output and was exported as a .csv file. The entire 2D path of the CoP trajectory was outputted to be used to create a 95% confidence path ellipse to output visual indication of range of movement in the forward, backward, left, and right directions. This was intended to facilitate clinical comparison between left and right side mobility. This ellipse could also be used to determine the total range of sway indicated by the total ellipse area and provide a measurable indication of strength, postural control, and mobility over time. This procedure utilizing a 95% confidence ellipse was influenced by previous studies of balance analyses [14]–[16].

The participant was observed by the PI's to assist in the event of a fall or other discomfort. External participants were not recruited for this study. Each trial was completed by a PI as a test of the program execution. User experience was not directly measured in this study.

D. Code Development

To integrate the force plate with our Unity™ project, C# code was written in Visual Studio [18]. Following the procedure outlined in the software development kit (SDK) [17], connection was first established with the force plate to transmit data using callbacks. This involved installing the FTD2XX.dll driver, and ensuring the BertecDevice.dll and BertecDeviceNET.dll libraries were properly loaded by the project [17].

Once the libraries were recognized, the status of the force plate was checked, and upon no errors being returned, data transmission began. CoP coordinates were then converted to player movement (left, right, forward, backward) within the VR environment by comparing the updated coordinate values after movement with the preceding values.

Upon completion of the VR task and the end of the session, the force plate object was disposed of within the code to release any connections that were still open and free all memory used by the library, including de-

registering all callbacks. Failure to do so may have instead caused memory or other resource leaks.

III. FINDINGS

The initial tests of integration between force plate movement and VR player movement were successful. The PI translational movement in the horizontal plane resulted in translational motion in the same directions within the VR environments. The VR environments were successfully compatible with the force plate integration.

This code successfully outputted CoP location on the force plate in real time. The output from the force plate was a .csv file containing the total CoP trajectory path in a 2D plane. These data in the .csv file can also be used to output a 95% confidence ellipse to compare preferential movement range visually and by using total ellipse area and area comparison between the left and right sides. These data can further be used to determine stability inferences such as velocity, displacement frequency, and others. The system requires further analysis to be expanded to such applications.

IV. FUTURE DIRECTIONS

This project can be expanded upon to provide quantitative balance measurements relevant to other physical therapy practices and research. This may include measurements of vestibular and proprioceptive function. Potential future applications may also include squatted obstacle maneuvering for eversion/inversion training, isometric heel raise reaching, tandem stance control, and single leg stabilization tasks. Additional research and combination with other measurement tools (e.g. EMG, strength testing, etc.) may be necessary to identify causal relationships in balance and postural control. In any physical therapy application, a user should be overseen by a clinician to ensure proper biomechanics and client safety.

V. CONCLUSION

This project provides a novel integration between planted sway movement on a force plate to VR player motion for postural control evaluation and training and advances efforts in contemporary physical therapy practices. The final product provides a portable, accessible, and significantly less expensive alternative to existing specialized postural control evaluation equipment such as the NeuroCom™ Balance Master System.

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