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Original Article

Development of a Balance System Including Virtual Reality Applications for the Evaluation and Improvement of Balance: Physiotherapy–Engineering Cooperation

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ABSTRACT

Objective: The aim of the study was to develop a balance evaluation and exercise system consisting of virtual reality-based software, which can be an alternative to the costly balance devices available in the market for the purpose of assessing balance and exercising in individuals at risk of falling and examining its effectiveness.

Methods: In the first stage of the study, software was developed to evaluate balance and make exercise applications by using the balance platform of the Nintendo Wii game console available in the market. Then, hardware was added to the developed software and this developed system was tested on 30 healthy individuals (17 women and 13 men) and compared with the valid and reliable Biodex Balance System.

Results: When the developed system was compared with the postural stability test of the Biodex Balance System, it was determined that the overall stability (rho = 0.831 *P* = .027), forward-backward stability (rho = 0.789 *P* = .032), and left-right stability (rho = 0.761 *P* = .037) results showed a good correlation. It was observed that the measurements made with both devices gave similar results for static postural stability.

Conclusions: We believe that the exercise system consisting of virtual reality-based software developed within the scope of the project, which is portable and of low cost with balance assessment and rehabilitative games, can be used safely and effectively in improving balance.

Keywords: Balance, virtual reality, assessment, exercise

Introduction

Balance is defined as the body's ability to keep the center of gravity on the support base. It is a complex sensorimotor control system that includes the integration of sensory inputs from the visual, proprioceptive, and vestibular systems and is the key to mobility.[1] Balance is affected by both the task undertaken and the environment in which it is performed. Different tasks and environments change the biomechanics and information processing needs for balance control. Balance disorders and related falls cause an increasing burden of disease with high costs on social services and health systems. It has also been demonstrated to increase the number of consultations, the usage of diagnostic imaging, and the requirement for emergency care.[2-4]

As health professionals, physiotherapists need to evaluate their patients' skills in many areas such as neurological, geriatric, and pediatric rehabilitation. Evaluation and improvement of balance is important in terms of increasing functional independence and reducing the risk of falling and developing secondary health complications in people with balance problems.[5] Clinical balance assessments can be divided into 3 main approaches: functional assessments, systems assessments, and quantitative assessments. While a functional assessment approach is used to assess fall risk and determine whether there is a balance problem, a systems approach and quantitative assessments are needed to design a specific treatment program and to identify the underlying cause of the balance problem.[6]

Although balance control is an essential part of daily activities, its complex and rapidly changing nature makes it difficult to evaluate effectively. There are several clinical tests and functional scales available to assess balance, gait, and fall risk, such as the Timed Up and Go test, One-Leg Standing Test, and Berg Balance Scale.[6] However, it is reported that even the Berg Balance Scale, which is known to have good sensitivity in

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evaluations, is insufficient in the measurement due to the complex and multifactorial nature of balance.[7] In recent years, various technologies have been developed, especially focusing on sensors, in order to perform balance and posture analysis.[8] The use of sensors can improve the data quality of tests and scales used in the assessments.[9] Unfortunately, it is not possible for every clinic to access these systems due to their costs. Based on these, it is seen that there is a need to develop easily accessible new systems that comprehensively evaluate the balance.

The aim of this study was to develop and investigate the effectiveness of a "balance assessment and exercise system consisting of virtual reality-based software," which can be an alternative to the balance systems available in the market.

Material and Methods

System Development

The balance platform of Nintendo Wii, a game console, was used to develop the balance assessment and exercise system in the first stage of the study. Four sensors on the platform were placed on the base of the new device (Figure 1). The distance between the sensors was set as 24 cm + 42 cm (from the sensor common points to the sensor midpoints). Since the middle parts of the sensors are movable, they were left blank, and the edges were attached with nails or a suitable mechanism. Contact of the electronic device box and cable ducts with the ground was prevented. The sensor height was adjusted accordingly. Because the device can measure up to 120 kg, it was ensured that the plastic material on the sensor feet is strong enough. Sensor placement of the developed balance platform is shown in Figure 2.

The size of the used electronic card is 10 × 8 cm. There are power and micro Universal Serial Bus (USB) outputs on the front, and a total of 6 Light Emitting Diode (LED) + sensor inputs on the backside of the card. There are suitable entrances on the sidewalls of the box. The height of the card is 15.3 mm including the Printed Circuit Board. There are 4 installation holes on the card, and locations can be taken from the dxf file. The card is screwed into the device box, and the screw hole is 3 mm in diameter. After the balance platform was completed, a prototype of the device was created by adding hardware to enable the patient to stand comfortably on the platform. The developed prototype is shown in Figure 3. The features of the device are summarized in Table 1.

Following the completion of the hardware, the integration with the software created for the evaluation and development of the balance

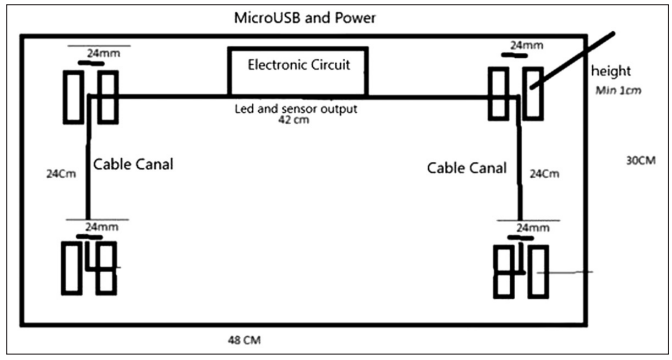

Figure 2. Sensor placement of the developed balance platform.

Figure 3. The first prototype of the balance device.

was provided. The evaluation software allows the examination of individuals' anterior–posterior and right–left weight shift ratios and postural stability. In addition, evaluation results can be reported (Figure 4). Rehabilitative game software including virtual reality applications was developed for the system in order to improve the balance. A total of 6 different game scenarios were created with the opinions of physiotherapists and engineers. The therapeutic aim of the developed games was determined to be bringing the center of gravity to the midline, controlling displacements in the center of gravity, shifting weight to the right, left, front, and back, and completing the given multi-task in

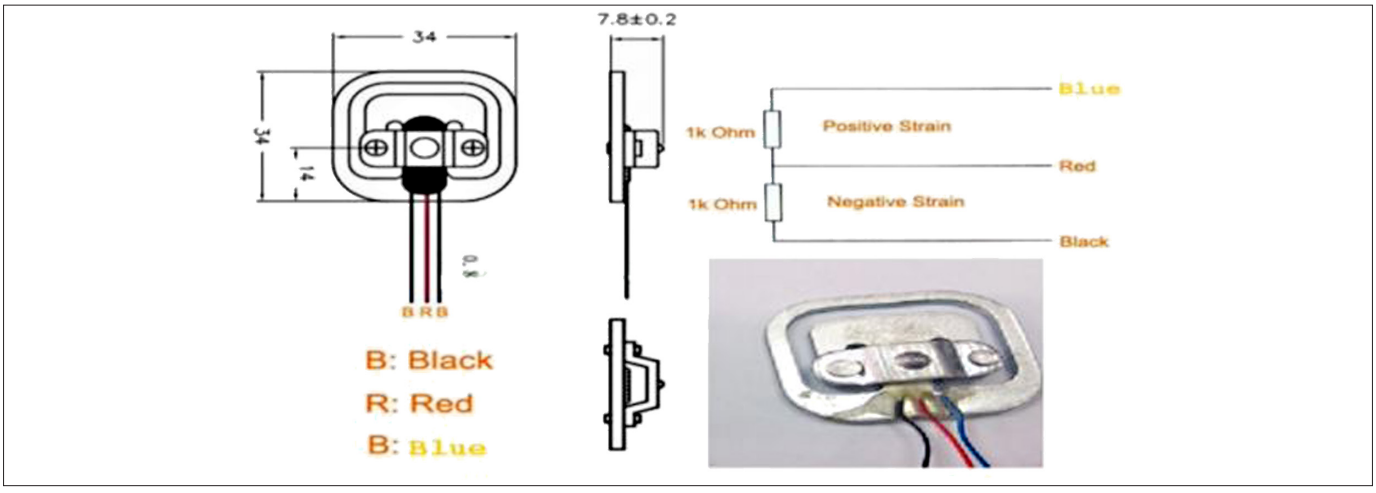

Figure 1. Utilized sensors.

Table 1. Features of the Developed Balance System	
Range of measurement	1-120 kg
Resolution	24 Bits
Sensitivity of sensor output	mv/v 1.0 ± 0.1
Power	Can be powered by USB
With adapter	7-36 V DC
Working temperature	(+5°C) to (+50°C)
Storage temperature	(+0°C) to (+80°C)
Humidity	20%-80% non-condensing
Dimensions (width × length × height)	320 mm × 500 mm × 40 mm
Interfaces	USB 2.0
	Bluetooth 2.1 (SPP profile)
	Wifi (host controller or client)
	LED indicators
	Buzzer

the target time by focusing attention within the game scenario. Three difficulty levels (beginner, intermediate, and advanced) have been created for all games.

Usability of the Developed Balance System

The usability of the developed balance system was evaluated at Istanbul Gerontechnology Research and Application Center (Ist-Getam) between January 2020 and September 2021 on participants aged 25-45 and without any diagnosed disease. The study was approved by the Istanbul Medipol University Non-Interventional Clinical Research Ethics Committee and conducted based on the Helsinki Declaration. Written informed consent was obtained from all participants.

Postural stability and postural sway of the participants were evaluated using the newly developed balance system and the Biodex Balance System, with eyes open and closed, respectively. All assessments were conducted by the same physiotherapist. The use of the Biodex Balance System was preferred in the study, as it was reported to be valid and reliable in the evaluation of postural stability and sway.[10,11]

In the postural stability test on both systems, the participant stood on the platform in an upright posture with the feet at hip level. The participant was asked to maintain the position of the round point symbolizing the center of gravity for 20 seconds while the platform was in a static condition. Overall, forward-backward and left-right stability and sway index values were obtained as a result of the evaluations.

Statistical Analysis

The Statistical Package for the Social Sciences software version 21.0 was used for the statistical analysis. Descriptive statistics were presented as mean and standard deviation. The normality of data distribution was assessed using the Kolmogorov–Smirnov test. The Mann–Whitney *U* test was used for the comparison of data between balance systems. Correlations between the variables were calculated using Spearman's correlation analysis. The level of statistical significance was set at $P < .05$.[12]

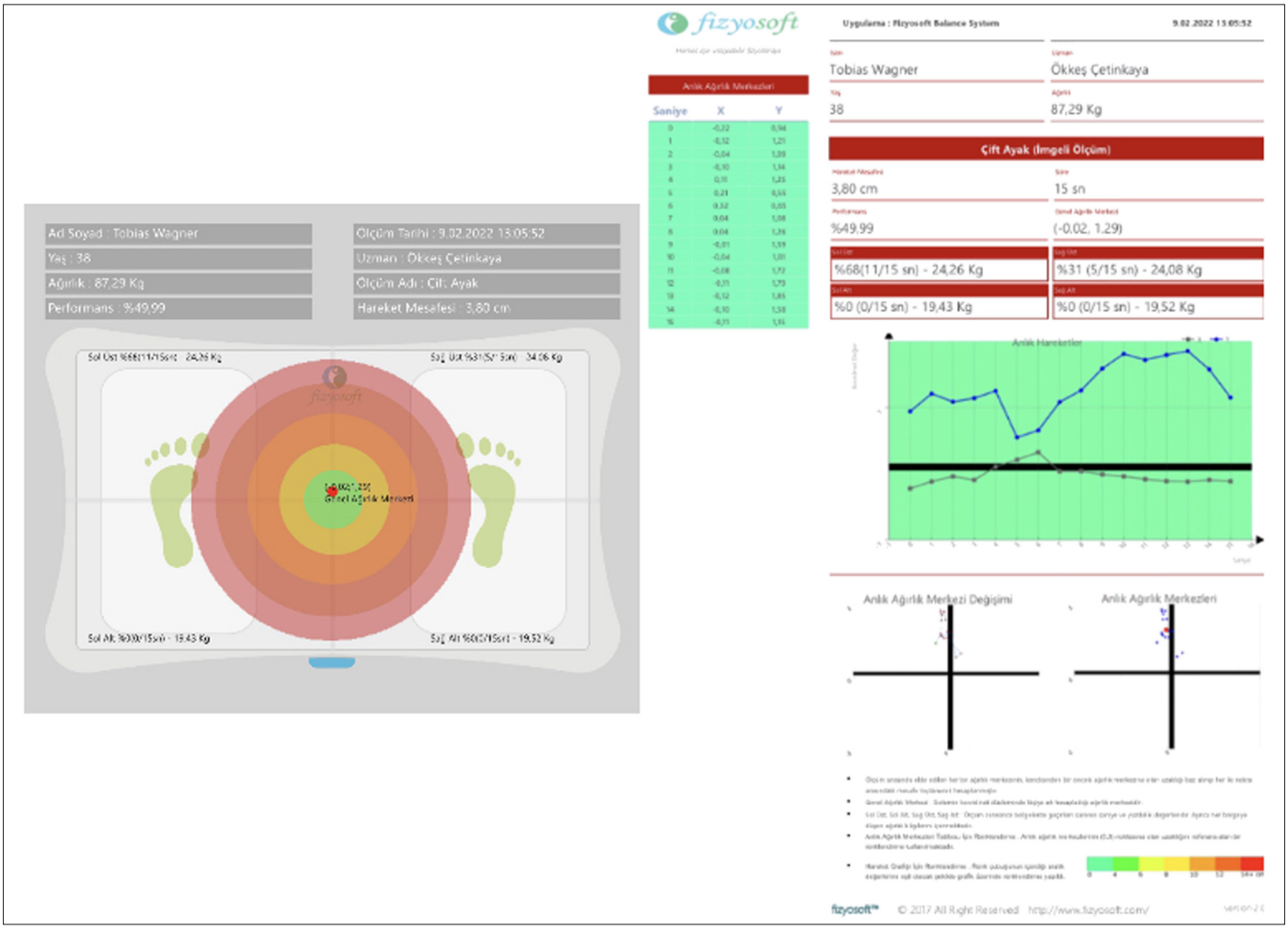

Figure 4. Example of the evaluation report of the developed balance system.

Table 2. Comparison of Postural Stability Results of the Participants

	Evaluations of Developed Balance System (n = 30) Mean ± SD	Evaluations of Biodex Balance System (n = 30) Mean ± SD	*t*	*P*
Overall stability index	0.26 ± 0.18	0.25 ± 0.12	1.174	.271
Forward/backward stability index	0.17 ± 0.11	0.16 ± 0.14	1.96	.68
Left/right stability index	0.19 ± 0.01	0.18 ± 0.02	0.537	.604
Overall sway index	0.29 ± 0.18	0.28 ± 0.15	1.150	.280
Forward/backward sway index	0.17 ± 0.15	0.15 ± 0.18	2.85	.019
Left/right sway index	0.25 ± 0.14	0.23 ± 0.15	1.893	.091

Table 3. The Relationship Between the Evaluation Parameters Obtained from the Devices

Developed Balance System/ Biodex Balance System	Overall Stability Index	Forward/Backward Stability Index	Left/Right Stability Index	Overall Sway Index	Forward/Backward Sway Index	Left/Right Sway Index
rho	0.831	0.789	0.761	0.822	0.712	0.706
P	.027	.032	.037	.024	.043	.035

Results

In this study, 30 healthy individuals between the ages of 25 and 45 were included to determine the validity and reliability of the balance evaluation part of the developed system. It was important that the included individuals did not have any diagnosed diseases and volunteered to participate in the study. Of the 30 individuals who met the criteria, 17 were females (mean age 32.14 ± 15.24 years) and 13 were males (mean age 31.17 ± 13.19 years).

After the evaluations with the newly developed balance system, the individuals were taken to the postural stability test of the Biodex Balance System, the validity and reliability of which has been proven. The results of the developed balance system and Biodex Balance System are shown in Table 2. It was observed that the evaluation results obtained from both devices were parallel to each other.

When the relations between the evaluation results obtained from the devices were examined, it was found that the results of overall stability (rho = 0.831, $P = .027$), forward-backward (rho = 0.789, $P = .032$), left-right stability (rho = 0.761, $P = .037$) showed a good level of correlation, and for static postural stability, similar results were obtained with both devices. In terms of sway index, it was concluded that the results of both devices were correlated with each other, and the measurements were compatible (Table 3).

Discussion

The purpose of this study was to develop a balance assessment and exercise system consisting of virtual reality-based software and investigate the effectiveness. The results showed that the developed balance system can evaluate the postural stability and sway of individuals similar to the Biodex Balance System.

A good balance assessment is very important for effective balance training. By determining the balance status or disorder of the individual before starting the treatment, the progress of the individuals can be monitored and recorded, and changes can be made in the exercise programs.[13] Various scales, clinical tests, applications, or systems are used to evaluate balance in physiotherapy and rehabilitation units.[14,15] Although scales and clinical tests allow balance assessment free of charge and in a short time, a detailed and comprehensive assessment cannot be made. In recent years, balance assessment applications are being developed with smartphones.[16] However, since the developed applications are built on the infrastructure of the existing device, they may not present as detailed result reports as the balance systems. In systems developed to evaluate balance, some parts provide objective evaluation such as force platforms, strain gauge sensors, and accelerometers.[17] Through these parts in the systems, clinicians and researchers can quantitatively follow the changes in the evaluations they made at different times.[13] Although most of the balance systems allow for detailed evaluation, they are not available in every clinic due to their expensiveness, space consumption, and usage difficulties.[18]

The developed balance system is different from other systems used in clinics due to providing real-time feedback on the balance performance from the screen during the evaluation, easy to use, cost-effectiveness, and the presence of a Turkish interface. Additionally, the system also offers treatment opportunities as well as evaluation of patients. Games developed for therapeutic purposes can enable the improvement of different balance parameters. Our patient feedback about the system, which can be improved in terms of evaluation parameters and therapeutic games, is also positive. Evaluating only the static balance and not including a dynamic surface can be counted among the deficiency of the developed system.

In this study, the developed balance system was compared with the validated Biodex Balance System. Although the results obtained from both systems are parallel to each other, we think that the developed balance system is more convenient and accessible for assessing postural stability and postural sway. The effectiveness of the developed system in evaluating and improving balance in the elderly or in individuals with neurological diseases at risk of falling can be investigated in future studies.

Conclusion

It is important that the virtual reality-based balance evaluation and exercise system developed within the scope of the project supported by the Turkish Academy of Sciences is a domestic and national product that is an alternative to the balance devices supplied abroad. Additionally, the collaboration of physiotherapy and engineering fields during the development of the system can be shown as an example of interdisciplinary work. Since the system allows treatment with virtual reality-based rehabilitation games besides evaluation, we think that patients will do their exercises in a more motivated way and physiotherapists can create rehabilitation programs with a new perspective.

Ethics Committee Approval: Ethics committee approval was received for this study from the Ethics Committee of Istanbul Medipol University (Date: February 22, 2017; Decision number: 440)

Informed Consent: Written informed consent was obtained from all participants.

Peer-review: Externally peer-reviewed.

Author Contributions: Conception, Design, Supervision – E.T; Funding – E.T., Y.Z.Y., A.B.O.; Materials – E.T., Y.Z.Y., A.B.O.; Data Collection and/or Processing – E.T., Y.Z.Y., A.B.O.; Analysis and/or Interpretation – E.T., Y.Z.Y., A.B.O.; Literature Review – E.T., Y.Z.Y.; Writing – E.T., Y.Z.Y., A.B.O.; Critical Review – E.T., Y.Z.Y.

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Conflict of Interest: The authors have no conflicts of interest to declare.

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