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Original Article

Design and evaluation of a multimodal balance training system

Zhan Zhao[1], Jian-Min Zhu[2], Hai-Po Cui[1], Mei-Jun An[3]

[1]Shanghai Institute for Minimally Invasive Therapy, University of Shanghai for Science and Technology, Shanghai 200093, PR China; [2]School of Mechanical Engineering, University of Shanghai for Science and Technology, Shanghai 200093, PR China; [3]Shanghai University of Medicine & Health Sciences, Shanghai 200120, PR China

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Abstract: Objective: Current balance training systems are designed exclusively for one particular type of training and assessment. Additionally, they comprise monotonous training programs. Therefore, patients in different stages of rehabilitation must use different balance training models from different manufacturers, resulting in high treatment cost. Furthermore, large spaces are required to accommodate the balance training machines, and doctors and physiotherapists have to learn to operate multiple machines. We aimed to design a multimodal balance training and assessment system that can accommodate the assessment and training of static, dynamic, reactive and proactive balance to satisfy individual needs. Methods: The difficulty associated with combining static, dynamic, reactive and proactive balance training in a single system was to use radial and circumferential driving mechanisms together with a clutch mechanism, whereby circumferential and radial drivers were installed in the base of the system to drive a compound foot plate system with interchangeable springs, in order to adjust stiffness using the clutch. Based on the kinematic equation, the influence of system parameters on the change of the body's center of gravity were evaluated. The parameters included the radial offset of the driving mechanism (r), circumferential angle of rotation (θ), height of the base of the balance training system (h), horizontal distance between the body's standing center of gravity and the center of the foot plate (R), thickness of the padding mat (ΔH) and inclination angle (α). Results: The difficulties associated with combining static, dynamic, reactive and proactive balance training models in a single system were solved using radial and circumferential driving mechanisms together with a clutch mechanism. The foot plate can swing back and forth within ±20° around the X-axis, swing left and right within ±20° around the Y-axis, swing diagonally within ±20°, swing 360° around the Z-axis, and adjust the height along the Z-axis. Furthermore, the inclination angle α, circumferential angle of rotation θ, and speed ($d\alpha/dt$ and $d\theta/dt$) of the system can be controlled in real time. Conclusion: The developed balance training system is suitable for patients in different stages of rehabilitation. By providing multiple functionalities, this system can ensure high use rates, reduce costs and save space.

Keywords: Balance training, rehabilitation, multiple functional modules, balance assessment

Introduction

The sense of balance (equilibrioception) is vital for everyday life as it allows the human body to remain stabilized [1, 2]. Balance can be divided into static and dynamic balance, and the latter may be further divided into proactive and reactive balance. Stroke survivors often exhibit balance-related sequelae [3, 4]. The equilibrioception significantly degrades in the elderly, particularly after the age of 70. This is the primary cause of falls among the elderly, which often trigger a cascade of severe medical issues [5-7]. Chen et al. [8] found that equilibrioception was positively correlated with independence in activities of daily living (ADLs). They found a strong correlation of the balance performance before and after balance training with independence in ADLs. Balance performance is usually assessed using observational, scale-based and instrument-based methods. In particular, the instrument-based approach is an objective and precise method to assess and train balance. The human sense of balance can be improved through balance training [3, 9], and targeted rehabilitation exercises can improve neurological muscle control and proprioception, activate the nervous system, and engage deep muscles to enhance balance and stability. To be specific, balance training programs involve progressive levels of difficulty: from static to dynamic balancing, eyes open to closed, large to small supporting surfaces, and proactive to reactive balancing. Reactive balance training can improve a person's sense of balance [7], and a patient must ultimately be able to cope with continuous disturbances to maintain gait stability. Since our surrounding environments have various types of slopes, patients must also be trained to maintain balance on both level and angled surfaces [10].

At present, most existing balance training systems can provide only one type of balance training (static, dynamic, reactive, or proactive) and tend to follow monotonous training programs. For example, typical proactive dynamic balance test assessment and training equipment includes the Y-Balance dynamic balance instrument [11, 12], Wobble balance board [13] and the PosturoMed® device [14]. Typical reactive dynamic balancing equipment includes HUBER® 360 [15] and Imoove [16]. Static and dynamic hybrid equipment includes NeuroCom SMART EquiTest® [17, 18] and the Biodex Balance System [19]. In addition, some equipment for proactive dynamic balance assessment and training has been recently developed, such as BalRoom [20], Roto.BiT3D [21], Lafayette Instrument [22], and Dyjoc Board Plus SV-200 [23]. Chang et al. [24] developed an electric actuator-driven single-degree-of-freedom (1DOF) oscillating plate. Fung et al. [25] developed a 6DOF motion platform. Baselizadeh et al. [26] developed a 2DOF parallel mechanism-driven platform that could be rotated in forward-backward and left-right directions. An et al. [9] designed a full-body tilting device. In addition, a 1DOF device that could be tilted back and forth was used for the assessment of the posture control adjustment ability of the human body under perturbations [27]. A rolling balance board with an adjustable radius and height was introduced for the assessment of balance stability in the sagittal plane of the human body [28]. A balance measurement assessment of the human body using two Kinect2 devices through self-programmed software and algorithms was presented [29]. Besides, virtual reality, as a new technology for balance training, has rendered the training more effective [3, 30].

When using any of the equipment mentioned above, each patient requires a different balance training instrument at various stages of their rehabilitation, leading to high cost. Furthermore, these existing training systems occupy a large area, and doctors and physiotherapists must familiarize themselves with many different balance training systems.

In this study, we aimed to develop a balance training system that can be used for static, dynamic, reactive and proactive balance training in order to solve the aforementioned problems with existing balance training systems and to progressively improve gait control and lower limb motor function in patients with balance disorders. As the proposed balance training system can be set to specific speeds and angles according to the needs of each patient, it can satisfy safety and effectiveness requirements. Additionally, difficulties that would arise from combining different types of structures, hardware and software are avoided. To summarize, we have designed an intelligent and entertaining balance training system that has adjustable motion amplitudes/frequencies and difficulty settings for patients with balance disorders.

Materials and methods

First, the design requirements and initial design of our balance training system were formulated by analyzing the deficiencies in existing balance training systems. Subsequently, a complete design was formulated, followed by structural refinement and model design. This was finally followed by virtual model assembly to construct a virtual prototype. The virtual prototype was used to evaluate the safety and functionality of the designed product. After the design was finalized, any design flaws were resolved. This process resulted in a balance training system that is capable of facilitating static or dynamic balance training, with adjustable angles of inclination and swaying speeds. The design has a modular structure consisting of several functional elements, including a frame, drive mechanism, transmission mechanism, supporting structure, foot plate, sensors and an electronic control system, as shown in **Figure 1A**. This modular design allows for future

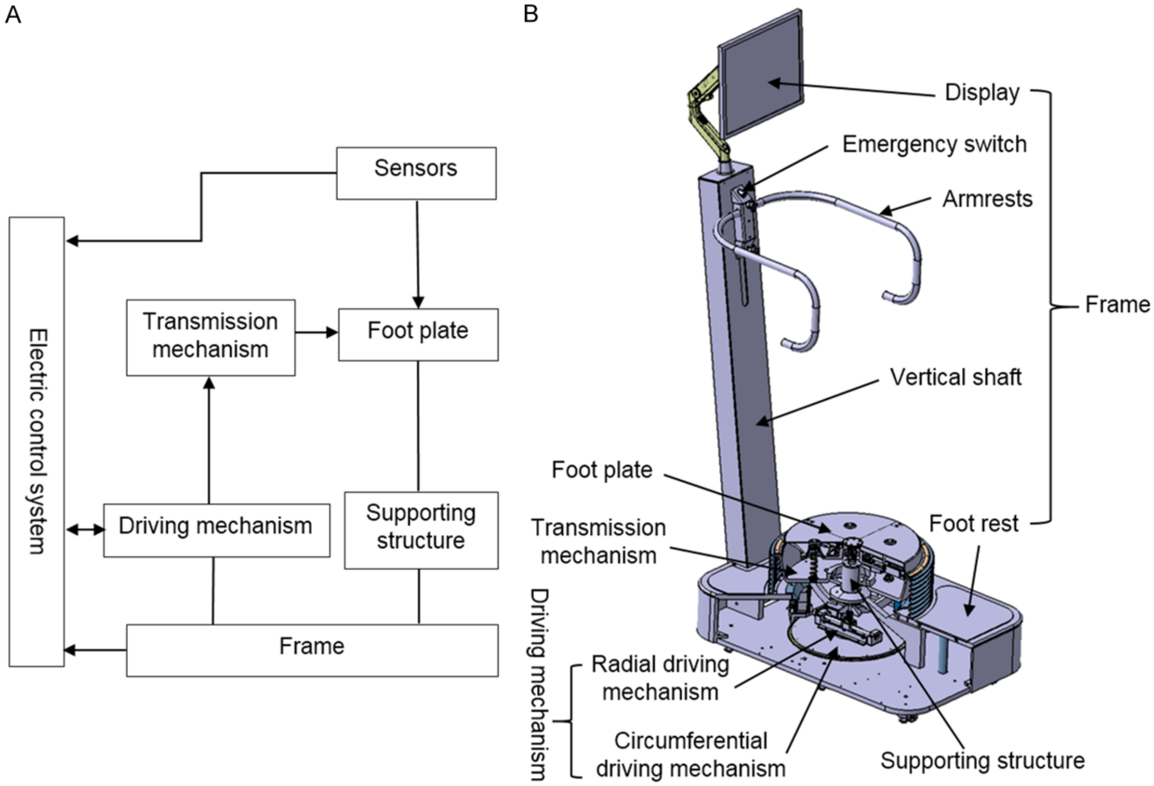

Figure 1. Balance training system. A: Modular design scheme, including a frame module, a support mechanism fixed on the frame and a drive mechanism, a foot plate mechanism mounted on the support mechanism using a universal joint, and a foot plate mechanism and a drive mechanism connected by a force transmission mechanism. B: 3D illustration of the design, including the frame, drive mechanism, support mechanism, foot plate mechanism and force transmission mechanism.

modification of the system by adding or removing modules as well as replacing them with improved versions. A three-dimensional (3D) illustration of the designed multimodal balance training and evaluation system is shown in **Figure 1B**. In this system:

• The frame consists of the display, emergency switch, arm rests, and foot plate.

• The mechanism is composed of radial and circumferential drivers. The radial and circumferential driving mechanisms comprise a screw nut on a linear rail and a motor that drives a gear, respectively.

• The transmission mechanism consists of a pair of telescopic cylinders that are connected to the driving mechanism underneath the system.

• The foot plate mechanism is connected to the supporting structure through a universal joint and consists of a foot plate with adjustable height and damping springs. The foot plate is linked by a clutch to the driving mechanism below, which either drives the foot plate into different static positions, causing it to sway left and right, or rotate in a circumferential direction. These movements could be used for static proactive, dynamic proactive and dynamic reactive exercises according to the corresponding direction and movement type (forward, backward, left, right, diagonal shaking and circumferential shaking).

The system's sensors include a force sensor and gyroscope on the foot plate, which allow the trajectory of the patient's center of gravity to be monitored, recorded, and displayed on the screen. Moreover, the data can be post-processed to show the trajectory of the center of gravity on the frontal, sagittal or transverse planes. In addition, data such as the center of gravity's height, speed, swaying frequency, displacement, total trajectory length and trajectory period can also be obtained. The gyroscope

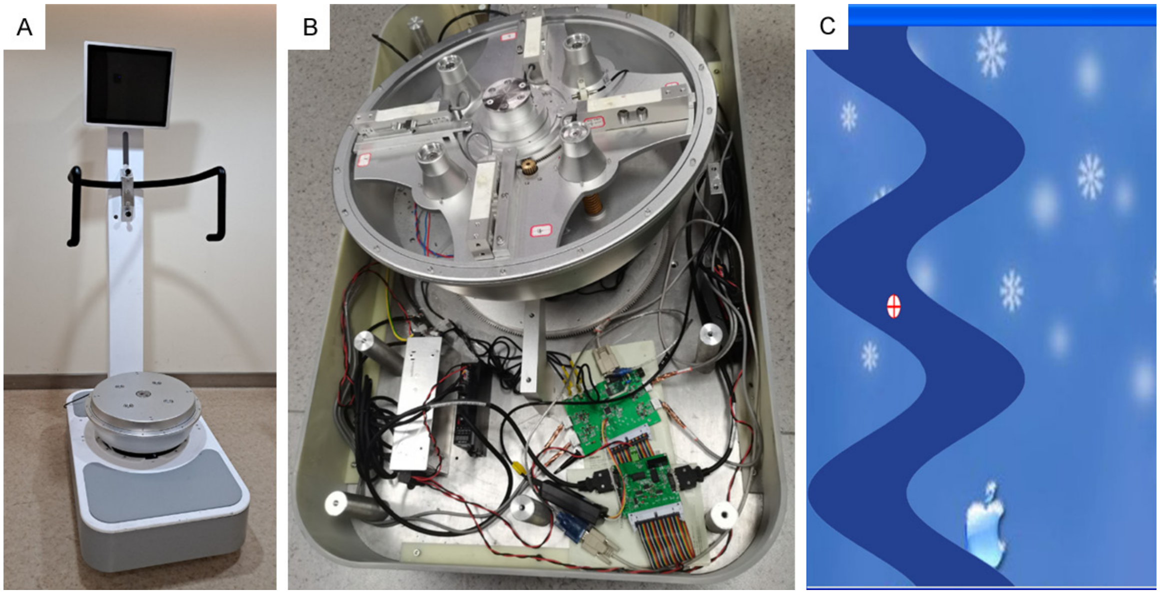

Figure 2. Photograph of the prototype. A: External view for the prototype with a width of 72 cm, depth of 132 cm, height of 202 cm, and weight of 162 kg. B: Internal view of the structure of the pedal box with the top cover removed. C: An interactive game scenario with the left-right balance control, in which the test subject drives the movement of the white dot with the red cross in the diagram by controlling the force distribution of the left and right feet; the assessment result is reflected by the score, which is determined by the distance of the white dot from the center curve of the blue curved road.

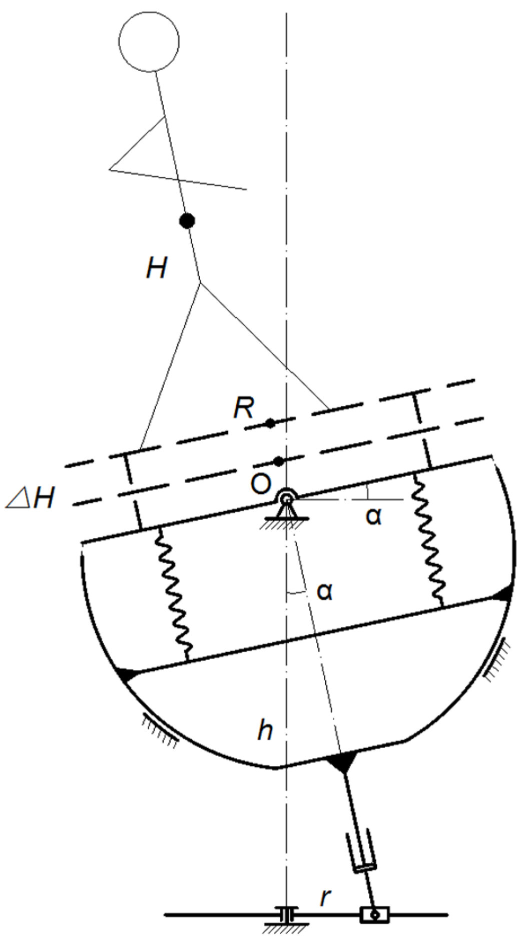

Figure 3. Kinematic diagram of the prototype, including four movable levers: a gear, the nut slider in a screw nut, a telescopic rod in a force transmission mechanism, and a foot plate mechanism.

records the inclination of the foot plate, which can be used to evaluate the stability of a patient at different gradients. A second gyroscope can be installed on the patient's waist to measure the speed and acceleration of the patient's center of gravity [31].

In the electronic control system, a gamified software interface is used for balance assessment and training, with a wide variety of functions, including reducing boredom during balance evaluation and training, and enhancing interactivity and enjoyment.

Results

A photograph of the constructed prototype is shown in **Figure 2**. The prototype has a width of 72 cm, depth of 132 cm, a height of 202 cm and a weight of 162 kg. The functions of this training system include (1) evaluation and static balance training on a horizontal or an inclined surface by setting the training system to the static mode, (2) dynamic balance training by closing the clutch and having the driving motor

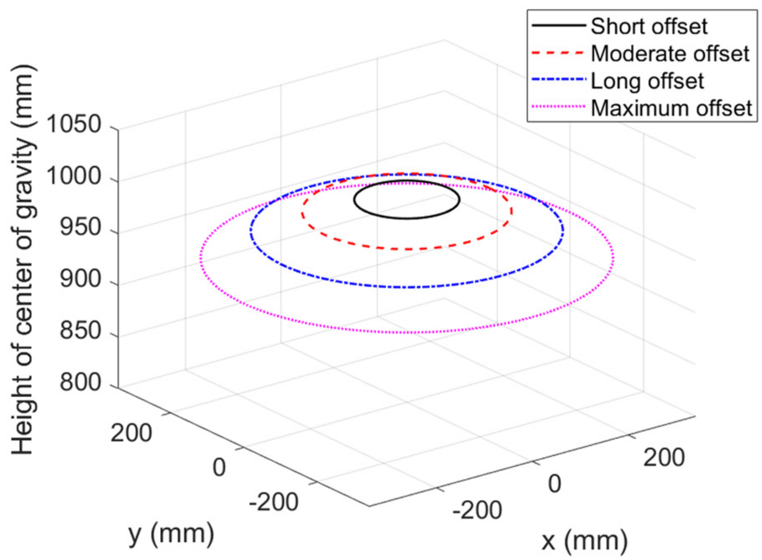

Figure 4. Effect of radial offsets (r) on the center of gravity of the human body.

to move the foot plate in right-left, forward-backward, or diagonal directions, (3) static proactive balance training by closing the clutch and using damping springs of an appropriate stiffness according to the patient's weight (the springs can be quickly changed by unscrewing the bolts on the foot plate), and (4) reactive balance training by closing the clutch and subsequently activating the driver to disturb the patient's center of gravity and unbalance the patient.

The inclination of the foot plate can be adjusted from 0° to 20°, and the magnitude of the changes in inclination can be adjusted in any direction during balance training. This allows rotations around the X- and Y-axis as well as vertical adjustments along the Z-axis. A kinematic diagram of the system is shown in **Figure 3**, where O is the origin of the coordinate system. The kinematic equations that govern the system are as follows:

$$x = [(H + \Delta H)\sin\alpha \pm R\cos\alpha]\cos\theta, \quad (1)$$

$$y = [(H + \Delta H)\sin\alpha \pm R\cos\alpha]\sin\theta, \quad (2)$$

$$z = (H + \Delta H)\cos\alpha \pm R\sin\alpha, \quad (3)$$

$$\alpha = \arctan(r/h), \quad (4)$$

Where x, y, and z are the coordinates of the body's center of gravity, H is the height of the center of gravity, ΔH is the thickness of the padding mat, r is the radial offset of the driving mechanism, h is the total height of the balance training system's base, α is the angle of inclination, θ is the circumferential angle of rotation ($\theta \in [0, 360°]$), and R is the horizontal distance between the body's standing center of gravity and the center of the foot plate.

During balance training, the center of gravity is governed by r, θ, h, R, and ΔH. **Figures 4-8** show how the center of gravity is affected by these parameters, where H is assumed to be 1000 mm based on the dimensions of the prototype and its governing kinematic equations. As r and θ are controlled by the electric motor, these parameters can be used to drive a passive motion and provide perturbations during static and dynamic balancing, respectively. The foot plate can swing back and forth within ±20° around the X-axis, swing left and right within ±20° around the Y-axis, swing diagonally within ±20°, swing 360° around the Z-axis, and its height can be adjusted along the Z-axis. Furthermore, the inclination angle α, circumferential angle of rotation θ, and the speed ($d\alpha/dt$ and $d\theta/dt$) of the system can be controlled in real time.

The center of gravity can also be moved in a circular oscillating trajectory by combining the radial and circumferential motions, as shown in **Figure 9**.

Discussion

This work presented a balance training system. First, its range in which α varies in the left, right, backward and forward directions can be configured in real time by adjusting the speed of the radial driving mechanism. Second, the stiffness of the damping springs can be adjusted to facilitate various proactive motions during balance training through the use of asymmetrical angles of inclination. Last, the velocity of the foot plate ($d\alpha/dt$ and $d\theta/dt$) can be

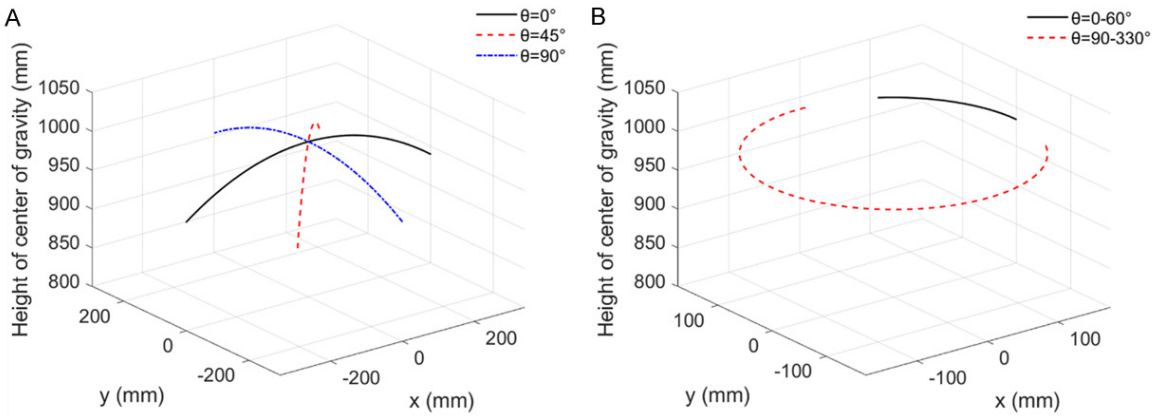

Figure 5. Effects of θ on the center of gravity of the human body. A: θ = 0° and left-right swaying by changing *r*, θ = 45° and diagonal swaying by changing *r*, θ = 90° and forward-backward swaying by changing *r*. B: θ = 0-60°, θ = 90-330°.

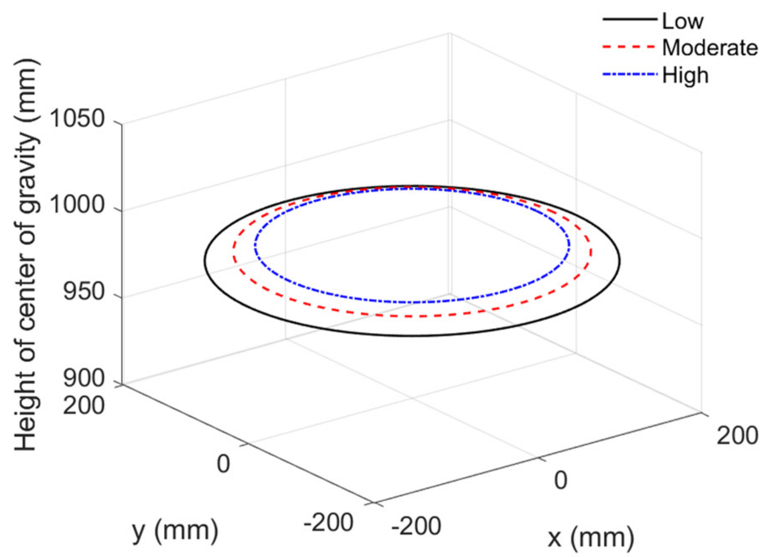

Figure 6. Effects of *h* on the height of the center of gravity (α = 10°).

varied by controlling the circumferential driving mechanism. The proposed balance training system can be used for static, dynamic, reactive and proactive balance training and evaluation.

When the circumferential drive mechanism of the system is controlled to stay at a certain position in the circumferential direction, the radial drive mechanism is driven to move reciprocally, i.e., the drive *r* varies within a certain range, and the human body can thus be swayed left and right, forward and backward, as well as diagonally. See **Figure 5A**.

When the radial drive mechanism of the system is controlled to stay at a certain position, the circumferential drive mechanism is driven to move reciprocally, i.e., θ is varied within a certain range, and the swaying motion of the human body can be realized, as shown in **Figure 5B**. The center of gravity of the human body during the training process can be controlled by changing the height of the device, h, changing the standing position of the human body, R, and adjusting the mat to different heights, ΔH. Thus, a variety of passive movement modes of the human body can be readily achieved. In addition, the swinging motion scope of the equipment and the speed of human body movement can be adjusted by controlling the motion scope and motion speed of the servo motor through the control system software. Active and passive training of the system can be performed by locking and releasing the pedals through the clutch mechanism. In this way, static, passive dynamic and active dynamic training of the human body can be realized. Specifically, when the clutch mechanism locks the pedals and the drive mechanism stops moving, static training of the human body can be carried out, and the plane of the pedals can be horizontal or con-

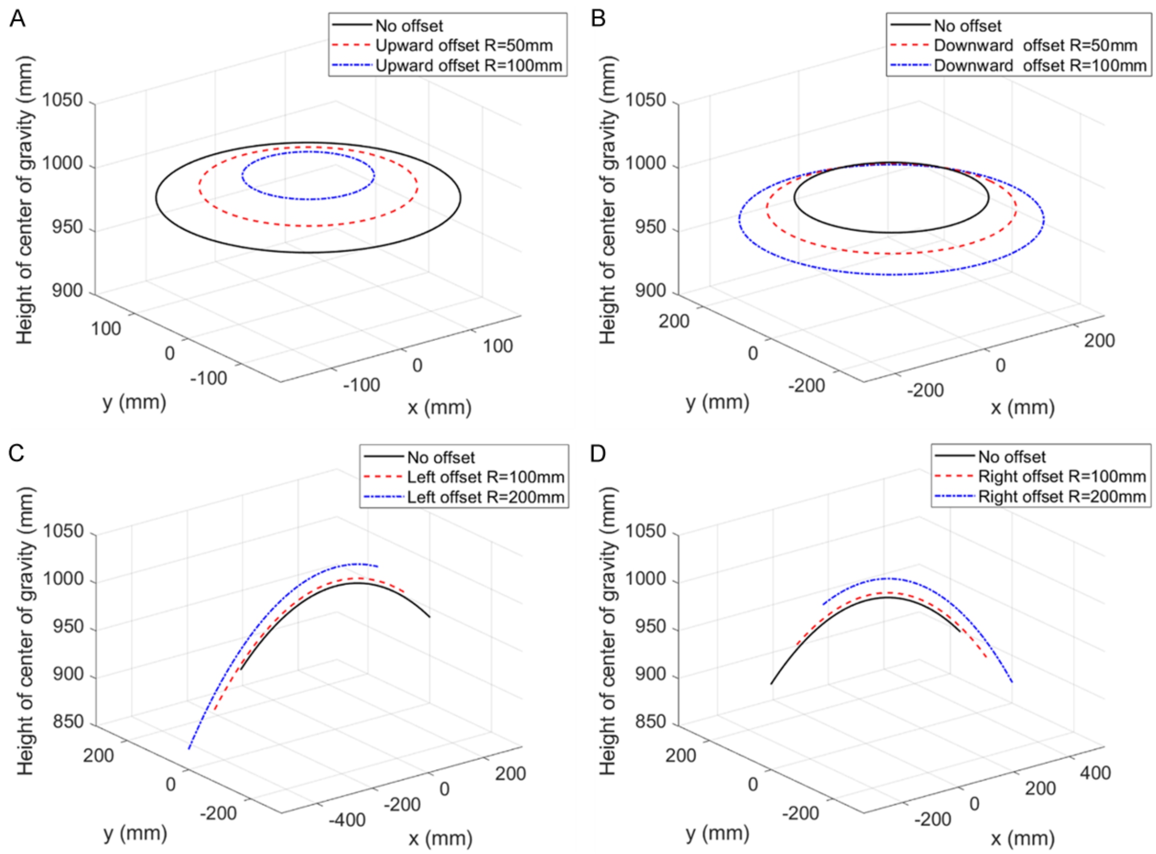

Figure 7. Effects of R on the height of the center of gravity. A: α = 10° with upward offsets R = 0, 50, and 100 mm. B: α = 10° with downward offsets R = 0, 50, and 100 mm. C: Left offsets R = 0, 100, and 200 mm. D: Right offsets R = 0, 100, and 200 mm.

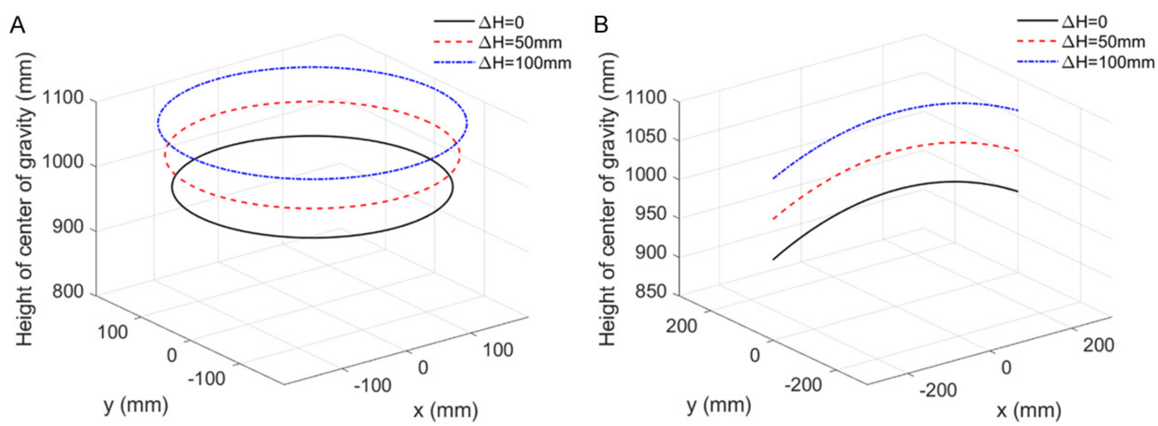

Figure 8. Effects of ΔH on the height of the center of gravity. A: Circumferential rotation with α = 10°. B: Swaying in the left-right direction.

trolled to become an inclined surface. In contrast, when the clutch mechanism locks the pedal and the drive mechanism drives the movement, passive dynamic training of the human body can be carried out, rendering an integrated active-passive and static-dynamic system. Therefore, the advantages of a high utilization rate and cost-effectiveness can be realized, and there is no need to purchase multiple equipments with different functions.

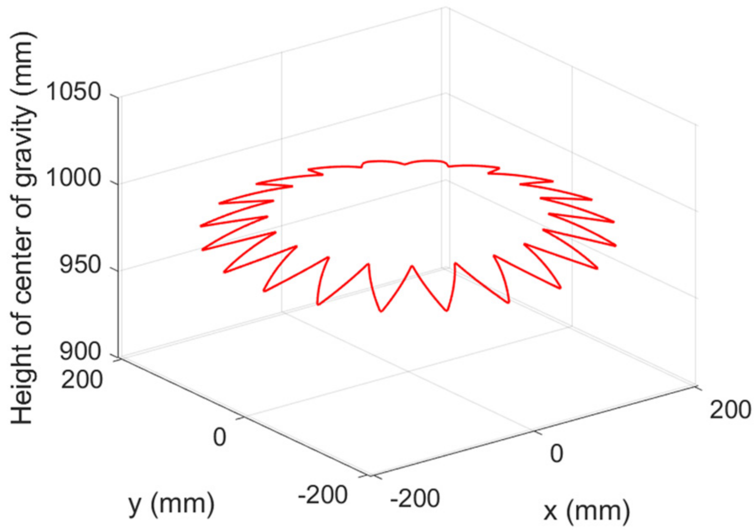

Figure 9. Effects of the circumferential and reciprocating radial motions on the center of gravity (α = 10°).

The proposed balance assessment training system not only enables static and dynamic balance assessment [16, 22] but also allows the static balance assessment to be conducted with the foot pedal in a nonhorizontal plane. Moreover, its dynamic balance assessment can be easily modified to suit patients with different body weights and needs by replacing the damping springs with different stiffnesses. Therefore, the designed system is more functional and powerful than existing systems. Compared to assessment training devices without an external drive [11, 12, 16, 19, 29], the proposed system is capable of passive and perturbation training of the human body. In addition, controlling its driving motion is easier than that of existing parallel mechanisms [21, 22, 24]. For example, if the human body sways left and right, only the peripheral drive mechanism needs to be controlled in the proposed system until the radial drive mechanism is rotated to the left and right directions, allowing the radial drive mechanism to independently control the reciprocating motion of the radial drive mechanism and achieve the swaying of the foot pedal in the left and right directions. In addition, the functional relationship between the inclination angle α and the position r of the screw nut is simple and clear, and the control principle is also not complicated. In contrast to previous reported systems [11, 12], the proposed system includes a gamified training software, which offers a better fun factor. Thus, it is especially suitable for patients undergoing long-term training assessments and is more likely to stimulate the interest of the test subjects, particularly in the elderly and children. Unlike the rubber foam pad or the device presented by Silva et al. [13], the proposed design has adjustable or replaceable inclination and elastic resistance so that it can better adapt to the needs of individuals at different training stages. Furthermore, the proposed design can be simplified and made into an active or passive training device to better suit the needs of family-oriented training. The proposed system is an integrated multi-use device, which can save space and reduce the cost needed to purchase multiple equipment for hospitals. It can save time for therapists in learning how to operate different devices, and lower the probability of misuse owing to different operating habits on different types of equipment. Because of COVID-19, the effectiveness of the developed system was evaluated only using a simulation analysis. In future studies, human trials will be conducted to further verify the performance of the proposed system.

Conclusion

This study introduced an easy-to-operate balance training system that can be used for six types of training: static balance training on level and angled surfaces, proactive balance training, passive balance training, proactive balance training with perturbations, hybrid proactive training and reactive balance training. Therefore, the proposed system can be used by patients with balance disorders in different stages of rehabilitation. However, it should be noted that a driver for up-down motions has yet to be installed in the prototype, which makes it impossible to perform changes in height. This shall be incorporated in subsequent design.

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Disclosure of conflict of interest

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Address correspondence to: Jian-Min Zhu, School of Mechanical Engineering, University of Shanghai for Science and Technology, 516 Jun-Gong Road, Shanghai 200093, PR China. Tel: +86-21-5527-1498; E-mail: jmzhu6688@163.com

References

[1] Held JP, Ferrer B, Mainetti R, Steblin A, Hertler B, Moreno-Conde A, Duenas A, Pajaro M, Parra-Calderon CL, Vargiu E, Jose Zarco M, Barrera M, Echevarria C, Jodar-Sanchez F, Luft AR and Borghese NA. Autonomous rehabilitation at stroke patients home for balance and gait: safety, usability and compliance of a virtual reality system. Eur J Phys Rehabil Med 2018; 54: 545-553.

[2] Yang WC, Wang HK, Wu RM, Lo CS and Lin KH. Home-based virtual reality balance training and conventional balance training in Parkinson's disease: a randomized controlled trial. J Formos Med Assoc 2016; 115: 734-743.

[3] Noh HJ, Lee SH and Bang DH. Three-dimensional balance training using visual feedback on balance and walking ability in subacute stroke patients: a single-blinded randomized controlled pilot trial. J Stroke Cerebrovasc Dis 2019; 28: 994-1000.

[4] Shigaki L, Vieira ER, de Oliveira Gil AW, Araujo CGA, Carmargo MZ, Sturion LA, de Oliveira MR and da Silva RA. Effects of holding an external load on the standing balance of older and younger adults with and without chronic low back pain. J Manipulative Physiol Ther 2017; 40: 284-292.

[5] Vistamehr A, Kautz SA, Bowden MG and Neptune RR. The influence of locomotor training on dynamic balance during steady-state walking post-stroke. J Biomech 2019; 89: 21-27.

[6] Hung JW, Yu MY, Chang KC, Lee HC, Hsieh YW and Chen PC. Feasibility of using tetrax biofeedback video games for balance training in patients with chronic hemiplegic stroke. PM R 2016; 8: 962-970.

[7] Okubo Y, Brodie MA, Sturnieks DL, Hicks C and Lord SR. A pilot study of reactive balance training using trips and slips with increasing unpredictability in young and older adults: biomechanical mechanisms, falls and clinical feasibility. Clin Biomech 2019; 67: 171-179.

[8] Chen IC, Cheng PT, Chen CL, Chen SC, Chung CY and Yeh TH. Effects of balance training on hemiplegic stroke patients. Chang Gung Med J 2002; 25: 583-589.

[9] An CM, Ko MH, Kim DH and Kim GW. Effect of postural training using a whole-body tilt apparatus in subacute stroke patients with lateropulsion: a single-blinded randomized controlled trial. Ann Phys Rehabil Med 2021; 64: 101393.

[10] Dutt-Mazumder A and Gruben KG. Modulation of sagittal-plane center of pressure and force vector direction in human standing on sloped surfaces. J Biomech 2021; 119: 110288.

[11] Johnston W, Dolan K, Reid N, Coughlan GF and Caulfield B. Investigating the effects of maximal anaerobic fatigue on dynamic postural control using the Y-balance test. J Sci Med Sport 2018; 21: 103-108.

[12] Johnston W, O'Reilly M, Liston M, Mcloughlin R and Caulfield B. Capturing concussion related changes in dynamic balance using the quantified Y balance test - a case series of six elite rugby union players. Annu Int Conf IEEE Eng Med Biol Soc 2019; 2019: 2063-2067.

[13] Silva PB, Mrachacz-Kersting N, Oliveira AS and Kersting UG. Effect of wobble board training on movement strategies to maintain equilibrium on unstable surfaces. Hum Mov Sci 2018; 58: 231-238.

[14] Kiss RM. A new parameter for characterizing balancing ability on an unstable oscillatory platform. Med Eng Phys 2011; 33: 1160-1166.

[15] Uzlasir S, Ozdiraz KY, Dag O and Tunay VB. The effects of stroboscopic balance training on cortical activities in athletes with chronic ankle instability. Phys Ther Sport 2021; 50: 50-58.

[16] Ha SM, Oh JS, Jeon IC and Kwon OY. The effects of surface condition on abdominal muscle activity during single-legged hold exercise. J Electromyogr Kinesiol 2015; 25: 28-33.

[17] Godzik J, Frames CW, Smith Hussain V, Olson MC, Kakarla UK, Uribe JS, Lockhart TE and Turner JD. Postural stability and dynamic balance in adult spinal deformity: prospective pilot study. World Neurosurg 2020; 141: e783-e791.

[18] Zhou Y, Kondo I, Mukaino M, Tanabe S, Teranishi T, Ii T, Oono K, Koyama S, Kanada Y and Saitoh E. Reliability and validity of a force-instrumented treadmill for evaluating balance: a preliminary study of feasibility in healthy young adults. Hong Kong Physiother J 2017; 36: 49-56.

[19] Elsotohy NM, Salim YE, Nassif NS and Hanafy AF. Cross-education effect of balance training program in patients with chronic ankle instability: a randomized controlled trial. Injury 2021; 52: 625-632.

[20] Pasma JH, Engelhart D, Maier AB, Meskers C, Aarts R, Schouten AC and Kooij H. Assessing

standing balance using mimo closed loop system identification techniques. Ifac Papersonline 2015; 48: 1381-1385.
[21] Taborri J, Salvatori S, Mariani G, Rossi S and Patanè F. BEAT: balance evaluation automated testbed for the standardization of balance assessment in human wearing exoskeleton. 2020 IEEE International Workshop on Metrology for Industry 4.0 & IoT 2020; 526-531.
[22] Brueckner D, Gopfert B, Kiss R and Muehlbauer T. Effects of motor practice on learning a dynamic balance task in healthy young adults: a wavelet-based time-frequency analysis. Gait Posture 2019; 70: 264-269.
[23] Wakano S, Takeda T, Nakajima K, Kurokawa K and Ishigami K. Effect of experimental horizontal mandibular deviation on dynamic balance. J Prosthodont Res 2011; 55: 228-233.
[24] Chang Z, Chen K and Liu R. Development of a dynamic force platform for human's balance testing. Proceedings of the Seventh Asia Interntional Symposium on Mechatronics 2016; II: 893-903.
[25] Fung J and Perez CF. Sensorimotor enhancement with a mixed reality system for balance and mobility rehabilitation. Annu Int Conf IEEE Eng Med Biol Soc 2011; 2011: 6753-6757.
[26] Baselizadeh A, Behjat A, Torabi A and Behzadipour S. Using robotic mechanical perturbations for enhanced balance assessment. Med Eng Phys 2020; 83: 7-14.
[27] Blanchet M, Marchand D and Cadoret G. Postural control adjustments during progressive inclination of the support surface in children. Med Eng Phys 2012; 34: 1019-1023.
[28] Molnar CA and Insperger T. Estimation of reaction time during human balancing on rolling balance board based on mechanical models. ASME 2020 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference 2020; V002T002A033 001-008.
[29] Lv Z, Penades V, Blasco S, Chirivella J and Gagliardo P. Intuitively evaluation balance measurement software using kinect2. Third International Workshop, REHAB 2015, CCIS 665 2017; 83-93.
[30] Brachman A, Marszalek W, Kamieniarz A, Michalska J, Pawlowski M and Juras G. Biomechanical measures of balance after balance-based exergaming training dedicated for patients with Parkinson's disease. Gait Posture 2021; 87: 170-176.
[31] Romtrairat P, Virulsri C, Wattanasiri P and Tangpornprasert P. A performance study of a wearable balance assistance device consisting of scissored-pair control moment gyroscopes and a two-axis inclination sensor. J Biomech 2020; 109: 109957.