DESIGN AND RESEARCH OF A MULTI-SENSORY INTERACTION THEORY BASED VIRTUAL REALITY BALANCE TRAINING SYSTEM

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Abstract. In order to optimize the design of ankle balance training equipment, this study issue uses multi-sensory interaction as the theoretical underpinning, taking into account the patients' subjective experiences and addressing the gaps and shortcomings in current products. Through trials, the benefits and efficacy of combining balance training with virtual reality technology to alleviate the symptoms of ankle instability have been demonstrated. This has given rise to new concepts and references for the design of ankle rehabilitation equipment.

Introduction. The joint that bears the most weight throughout the body is the ankle joint. However, there is a very high prevalence of ankle joint injuries during routine exercise [1]. Ankle ligament tears, significant swelling, and discomfort are all symptoms of most ankle joint injuries [2]. Additionally, because of the existing lack of knowledge regarding the secondary issues brought on by ankle sprains, people often resume their normal activities as soon as the pain and swelling subside [3], which can result in more serious ankle injuries [4]. In clinical medicine, strengthening proprioception through balance training is the most effective way to treat ankle injuries [5]. Balance training, as opposed to other forms of rehabilitation, has been shown by Ma X. J. and a number of other researchers to more effectively restore patients' ability to balance [6-7].

The goal of this study is to improve ankle rehabilitation products and offer new design ideas and methods for the design of rehabilitation products by integrating virtual reality technology into the balance training process.

Methods. In this study, a virtual rehabilitation system is created that combines virtual reality technology with balance training tools. Through the training, users can engage in a 3D parkour game. In Figure 1, the system framework is displayed.

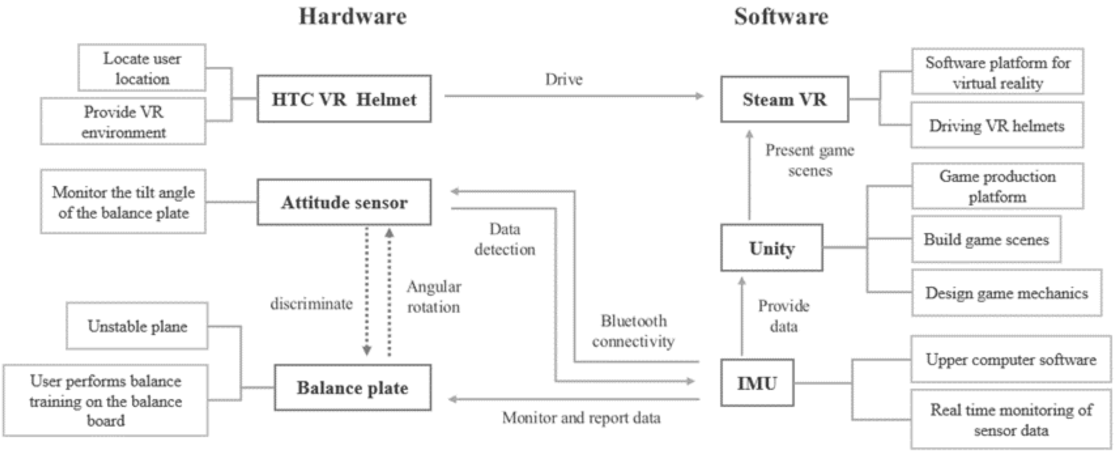


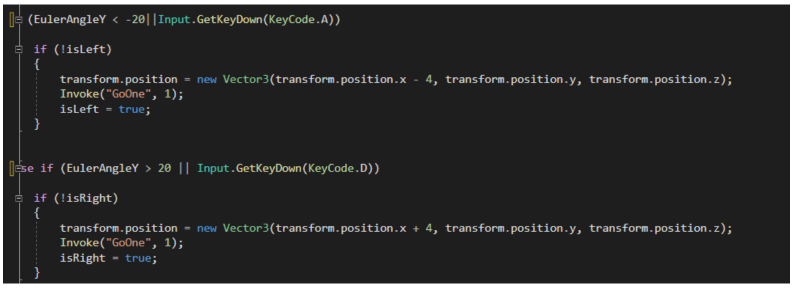
Figure.1. System Framework

The game's scenario is designed in the form of a cartoon village, complete with little dwellings, open areas, streets, and roadblocks like stones, stakes made of wood, and colored flags. The patient's ability to sidestep barriers as they arise is the primary criterion. As depicted in Figure 2, a balance board with sensors controls all dynamic game changes, allowing the patient to finish the game's objectives by pressing the board in all directions.

Figure.2. Virtual Game Scene

The system's gaming is made possible by technology like the balance board, the posture sensor, and IMU software. First, the sensor is fixed in the middle of the balancing plate, and the upper computer program IMU will show changes in the sensor's data. Set the sensor's starting spatial coordinate axis. The sensor will upload the angle change to the IMU software as the balance board rotates.

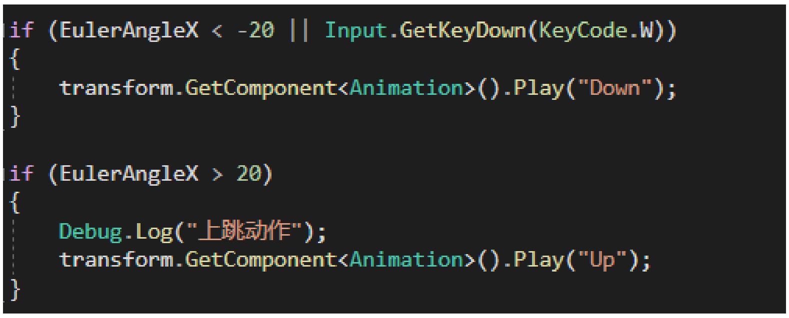
Second, the position of characters in the game can be altered by using the angle changes in IMU through code. The ankle's inward and outward movements are represented by the balance board's rotation along the Y-axis. The character's position in the game is unchanged in the Y and Z directions when the Y-axis rotation angle is larger than 20° or less than -20°, but moves right or left by 4 units in the X direction, as seen in Figure 3.



```
 (EulerAngleY < -20||Input.GetKeyDown(KeyCode.A))

 if (!isLeft)
 {
     transform.position = new Vector3(transform.position.x - 4, transform.position.y, transform.position.z);
     Invoke("GoOne", 1);
     isLeft = true;
 }


se if (EulerAngleY > 20 || Input.GetKeyDown(KeyCode.D))

 if (!isRight)
 {
     transform.position = new Vector3(transform.position.x + 4, transform.position.y, transform.position.z);
     Invoke("GoOne", 1);
     isRight = true;
 }
```

Figure.3. Code for character left and right movement

To simulate the ankle's toe flexion and back extension, the balance board rotates along the X-axis. The Up or Down command in Unity's Animation is activated and the game character will jump or squat when the X-axis rotation angle is larger than 20°or less than -20°, as seen in Figure 4.



```
if (EulerAngleX < -20 || Input.GetKeyDown(KeyCode.W))
{
    transform.GetComponent<Animation>().Play("Down");
}

if (EulerAngleX > 20)
{
    Debug.Log("上跳动作");
    transform.GetComponent<Animation>().Play("Up");
}
```

Figure.4. Code for character jump and squat movement

Experiment.

Material.

The HTC VIVE VR helmet is the apparatus utilized in this experiment. The IM600 posture sensor is utilized in this experiment. It can be used to detect changes in VR device's posture.

Participant.

In order to eliminate major disparities in ankle joint dynamics that could ultimately result in experimental errors, both males and females were included in the selection range of participant s in this experiment. Age differences were also minimized. The particular standards are as follows:

- The participants have at least one prior experience of a serious ankle sprain, which occurred 12 months prior to the time of this questionnaire survey, and which was accompanied by symptoms including pain and swelling, making it impossible for me to engage in everyday activities for at least one day;
- There was no ankle joint damage within six months;
- The Cumberland Ankle Instability Tool (CAIT) score ≤ 24.

Questionnaires were distributed to college students, and 20 qualified volunteers (including 7 men and 13 women) were chosen to participate as the experiment's experimental participants.

Process.

This experiment will run for five days straight. Using a training tool that blends virtual reality with a balancing training board, or the Gobetters board, the experimental participants are randomly assigned into two groups: the experimental group and the control group. Exercise the balance for 15 minutes on the different balance boards. In order to avoid obstacles in the virtual gaming scenario, members of the experimental group had to tread on and press the imbalance board while standing on a balance training device and donning VR helmets. Participants in the control group were instructed to stand on Gobetters board. The CAIT test must be completed by the participants on the first and last days of the trial, as well as the Y-balance test of both lower limbs.

The mechanical engineering school's lab at Donghua University was the setting for the experiment. The Y-balance test experimental procedure is as follows:

Take note of the participants' lower limb lengths. The participants are instructed to stand with their hands akimbo on the ground, mark the location of the anterior superior iliac spine (bony protrusions on both sides of the hip joint), mark the location of the ipsilateral inner ankle, measure and record the distance from the anterior superior iliac spine to the midpoint of the ipsilateral inner ankle, and record it as the length of the lower limb.

The participants should stand at the beginning posture with their hands in front of them, thumbs pointing toward the red reference line. The other foot should be extended as far as possible in the front, rear outer and rear inner directions indicated on the ground. The greatest distance that the foot tip can be from the ground in all three directions should be marked and measured with an accuracy of 0.5 cm.

Replace the opposite leg and record the results. According to Figure 5.

Figure.5. Y-Balance Test

The degree of ankle stability can be determined using the CAIT test, a professional subjective grading scale. The nine items that make up the CAIT scale ask patients how they feel about their ankle joint when performing routine activities including walking, running, and leaping. The degree of ankle stability is closely correlated with the score obtained on the CAIT scale, which awards a total of 30 points. The subject's ankle joint is more stable the higher the score. Researchers identified a score of less than 27 as the potential for functional instability in the ankle joint using the body of available literature. The presence of ankle instability will be determined if a unilateral ankle joint has less than 24 points. Participants are required to complete the CAIT self-evaluation assessment both prior to and following the experimental intervention.

Results. The Y-balance experimental data determines the total score and bilateral difference of both legs based on the recorded results, taking into account the participants' maximal extension in each direction, as shown in Table 1. The calculation formula is as follows:

$$\text{Unilateral leg comprehensive score} = \frac{a+b+c}{\text{Limb lengths}*3} *100\%$$

$$\text{Bilateral differences} = \frac{(a1+b1+c1)-(a2+b2+c2)}{(a1+b1+c1+a2+b2+c2)/2} *100\%$$

a1, b1, c1, a2, b2, c2 represent the distance that the left or right foot extends in three directions

After the experiment, both groups of participants' Y-balance test results improved. When compared to before the experiment, the control group's Y-balance test results were considerably higher in the posterior outer direction of the right leg ($P <0.05$), but the test results for both legs in the other directions were not statistically significant ($P>0.05$). Compared to before the intervention, the test results of the left leg of the experimental group showed significant variations in the posterolateral direction ($P<0.05$), and a very significant difference in the posterolateral direction ($P<0.01$). In comparison to before the intervention, the right leg displayed significant alterations in the anterior, posterolateral, and posterolateral directions ($P<0.01$). After the experiment, the comprehensive score of the legs in the experimental group revealed a significant difference ($P<0.01$). There was no statistical significance ($P>0.05$) in the bilateral differences between the experimental group and the control group, which were both less than 5%.

Table.1. Y-Balance experiment results

Test indicators	Direction	Group	n	Before experiment	After experiment
Test results in all directions of the left leg	ANT	Experimental group	10	65.6±5.63	71.2±6.47
		Control group	10	86.8±8.35	71.5±8
	PLAT	Experimental group	10	69.85±6.29	78.4±5.89*
		Control group	10	72.45±9.77	73.3±9.21
	PEMD	Experimental group	10	64.4±5.1	79.25±6.58**
		Control group	10	64.85±6.87	70.05±7.04
Test results in all directions of the right leg	ANT	Experimental group	10	65.05±4.7	71.45±6.08**
		Control group	10	69.45±5.7	71.5±5.87
	PLAT	Experimental group	10	68.55±5.78	77.6±7.76**
		Control group	10	71.15±6.66	76.75±5.68*
	PEMD	Experimental group	10	62.95±4.43	75.7±6.05**
		Control group	10	66.2±6.21	70.7±4.71
Comprehensive rating	Left leg comprehensive score	Experimental group	10	0.76±0.05	0.87±0.07**
		Control group	10	0.79±0.08	0.83±0.06
	Right leg comprehensive score	Experimental group	10	0.75±0.05	0.85±0.07**
		Control group	10	0.8±0.07	0.85±0.06
	Bilateral differences	Experimental group	10	0.05±0.03	0.03±0.02
		Control group	10	0.05±0.02	0.05±0.05

Table 2 displays the results of the CAIT test for the two groups. Before the experiment, there was no appreciable difference between the two groups (P>0.05). The CAIT scores of the two groups were higher following the experimental intervention. Through intragroup comparison, it was discovered that the experimental group's scores were significantly higher after experimental intervention than they had been before (P<0.05), but that there had been no significant change in the data of the control group before and after the experiment (P>0.05).

Table.2. CAIT self-evaluation experiment results

Group	n	Before experiment	After experiment
Experimental group	10	19. 2±4. 13	22. 5±1. 96*
Control group	10	18. 6±3. 03	19. 5±3. 06

Discussion.

- The majority of the current balance training devices on the market communicate with users by touch, and on this foundation, visual and aural interaction modes are added, giving users the opportunity to access a variety of emotional experiences through various sensory channels. Patients' training content can be customized by creating road impediments, which eliminates the issue of patients frequently failing to complete training requirements during autonomous training. Patients benefit from the effective and advantageous rehabilitation approach. Additionally, the more comforting and calming the pictures and music, the more interested the patients will be to train, the richer the training material will be, and the less pain the patients will experience while training. As a result, utilizing virtual reality technology has benefits over using just one balancing training product.
- Conclusions can be drawn through experiments. Compared to currently available balance training boards, training tools that integrate virtual reality and balance training can greatly raise patients' awareness of the functional stability of their ankle joints while also enhancing patients' dynamic balance control ability.

Conclusions. The goal of the study is to provide multi-sensory interactive rehabilitation training by incorporating virtual reality technology into training for ankle stability. Using hardware like posture sensors and software like Unity, a rehabilitation system for the ankles was created, and objective and subjective professional experiments were used to confirm the system's efficiency. Multi-sensory interaction was suggested to be achieved on the balance training product gadget, which can better stimulate patients' training willingness and greatly increase the patients' ankles' ability to manage their balance and modify their posture. This study offers fresh approaches and ideas for making ankle rehabilitation solutions even better.

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