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Utilizing Digital Therapeutics Technology to Improve Willingness to Actively Participate in Gait Rehabilitation Training and Increase Interest in Treatment

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Abstract: In this study, we demonstrated the feasibility of 'Morning Walk S200' as a rehabilitation training tool using an eXtended Reality (XR) system for those who are in need of gait rehabilitation. The lower limb rehabilitation training robot performs repetitive training according to the specified input gait trajectory. While the robot constructs passive training, it is crucial to encourage patients to engage in active training in order to enhance treatment effectiveness. 'Morning Walk S200' utilizes a diverse range of VR (Virtual Reality) experiences—such as walking through Saryeoni Forest in Jeju Island, landscaping, a baseball batting game, and the Blue and White Flag game—all designed to improve patients' active participation and increase interest in their treatment. Additionally, this study includes several papers that validate the technical efficiency of "Morning Walk S200" and examine the VR content. We suggest that developing innovative and engaging treatment options is essential, highlighting the need to utilize VR content effectively to enhance the outcomes of gait rehabilitation training.

Keywords: Gait; Rehabilitation Robot; Robot-Assisted Training; Virtual Reality (VR)

1 INTRODUCTION

Digital therapeutics refers to a specific type of software that is designed to treat diseases and improve health. This generally includes bio-healthcare or medical devices that utilize applications, games, and virtual reality or augmented reality (VR/AR) technologies [1]. Numerous studies have been conducted on the treatment and rehabilitation of vestibular dysfunction using virtual reality and Head-Mounted Displays (HMDs). A study has been published showing the effectiveness and safety of vestibular rehabilitation training using a gaming display created with Unity [2]. Dascal's research also validated the utility and efficacy of VR for three major medical conditions: pain management, eating disorders/obesity, and cognitive/rehabilitative exercises among hospitalized patients from 2005 to 2015 [3]. A study on "Effects of a virtual reality exercise program using video games on the motor performance of the elderly", proved that virtual reality exercise programs are significantly effective in improving strength, balance, and gait in the elderly [4]. Therefore, this paper aims to introduce the 'Morning Walk S200' developed by Curexo™, along with various VR contents used for VR rehabilitation therapy, one of the main technologies in modern rehabilitation therapy.

2 THEORETICAL BACKGROUND
2.1 Digital Therapeutics (DTx)

An analysis of domestic research trends related to the development of Digital Therapeutics (DTx) in the field of communication disorders defines digital therapeutics as software medical devices that provide evidence-based therapeutic interventions to patients to prevent, manage, and treat medical disorders or diseases [24]. According to Samjung KPMG's Investment Trends and Future Strategies for Third-Generation New Drug Digital Therapeutics, the following five technologies are considered the key digital therapeutics [5]:

1) Mobile and PC-based Apps: Therapeutic applications are provided as mobile and PC-based applications with a variety of content. These apps represent the most basic form of digital therapy.
2) Virtual and Augmented Reality (VR and AR): Virtual Reality Therapy (VRT) employs the use of VR technology for therapeutic purposes, including psychotherapy, neurological rehabilitation, and musculoskeletal rehabilitation.
3) AI/Big Data: Healthcare big data can be analyzed to recognize specific patterns that help predict and diagnose diseases or provide personalized treatment plans for patients.
4) Brain-Computer Interface (BCI): A collection of interface technologies that utilize brain waves to control computers or machines. The goal is to improve neurological communication between the brain and muscles in conditions such as Lou Gehrig's disease, stroke, spinal cord injury, and cerebral palsy.
5) Games: Utilizes adaptive algorithms to provide a personalized treatment and rehabilitation experience for patients, incorporating various effects and rewards to engage patients and enhance their motivation.

As such, the continuous evolution of devices and networks has enabled VR rehabilitation therapy to be delivered. Digital Therapeutics (DTx) has advantages over classical therapies [22]. First, DTx can be delivered digitally, free from space and time constraints. Second, as a software-based therapy, DTx can quantify and standardize both the data from the patient and the data from the expert physician. Third, DTx is a personalized service and treatment.

2.2 Extended Reality (XR)

Immersive content is defined as digital media that employs immersive technologies to engage the human senses, providing information and creating a nearly realistic sense of presence for users [23]. Extended Reality is one form of immersive content, which combines Virtual Reality and Augmented Reality to fully immerse users within a virtual environment. In addition to VR and AR, games and PC-based apps are the key technological elements of digital therapeutics. When these elements are fused and expanded, they leverage XR technologies. XR digital therapies show great promise for rehabilitation training, particularly for people who acquire gait and mobility abnormalities.

2.3 HMD

To experience VR, AR, and MR, you need a specialized device. Among the various devices, the most popular and fastest-growing device is the Head Mounted Display. These devices are worn over the head, immersing you through a new virtual world right in front of your eyes. Google was the first company to enter the HMD market, followed by Microsoft, Meta (formerly Facebook), Samsung, and others. Additionally, various innovative HMD devices are being developed exponentially. The platform market is evolving through a sequence of advancements in computers, the Internet, and mobile devices, with HMDs now emerging as the fourth major technological platform. VR and AR technologies are developing at a rapid pace and converging across various fields. In the healthcare sector, these VR and AR technologies are being utilized, including the following [25]:

- Life Care Sector: Healing VR content, Sports VR, Health Avatars, etc.
- Healthcare: 360-degree Surgical Video Services, Dental Simulators, Rehabilitation, etc.

Through these HMD devices, 'Morning Walk S200' offers users an enhanced sense of immersion in virtual reality, potentially increasing their interest and commitment to rehabilitation training.

2.4 Robot Rehabilitation

Rehabilitation is divided into physical therapy, occupational therapy, cognitive therapy, speech therapy, psychotherapy, pain therapy, and robotic therapy. Furthermore, robotic rehabilitation is divided into therapeutic goals, as shown in Fig. 1.

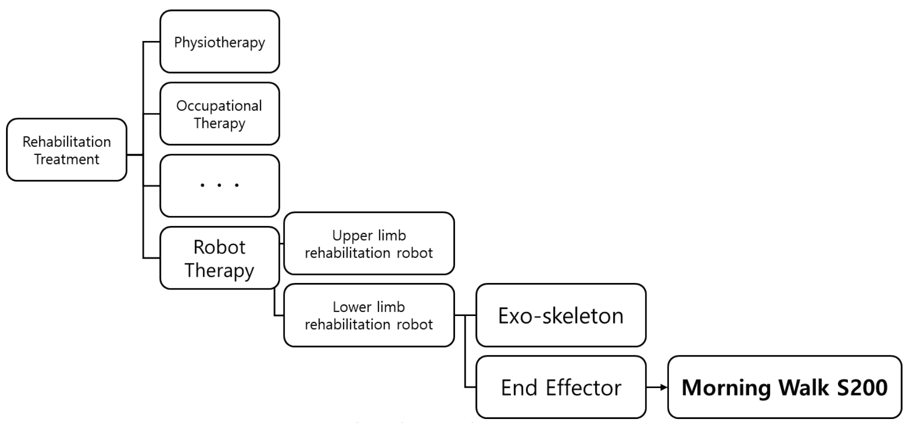

Figure 1 Classification of rehabilitation robots

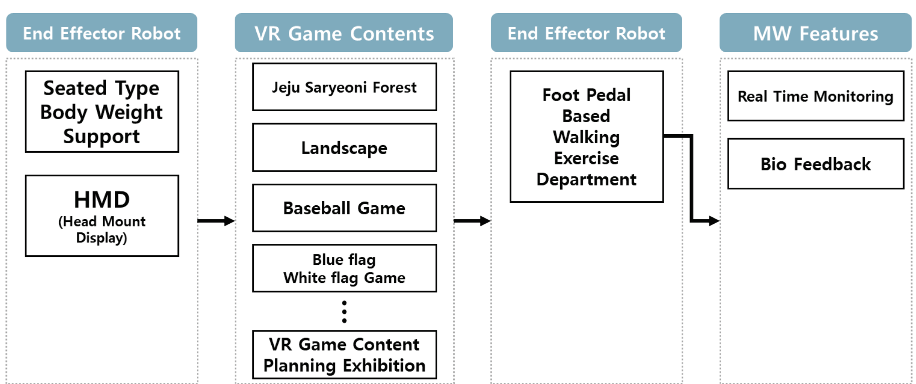

Figure 2 Morning Walk S200 system structure diagram

Rehabilitation robots are categorized into two types, upper-limb rehabilitation robots and lower-limb rehabilitation robots. One example of a lower-limb rehabilitation robot is ‘Morning Walk S200’, which focuses on gait rehabilitation targeting the lower limb. This training is conducted through an input protocol programmed into the robot. In order to perform repetitive and intense gait training without additional space, it is essential for the patient to actively participate in the training as the robot follows a specific gait trajectory. To encourage active participation, ‘Morning Walk S200’ utilizes VR content, which enhances patient participation and increases their interest in therapy [11-13]. This study introduces ‘Morning Walk S200’ and describes how it utilizes VR as a key technological element of digital therapeutics in rehabilitation.

3 SYSTEM DESIGN
3.1 System Structure

Fig. 2 is a simplified system block diagram of the ‘Morning Walk S200’. ‘Morning Walk S200’ helps patients of all ages, from those who cannot walk to those who need gait rehabilitation training. After recognizing the user's motion using the Kinetic system camera loaded on the ‘Morning Walk S200’, the user must board on top of the robot. The user (patient) can receive VR therapy through a separate HMD and a screen placed in front of the user.

3.2 Use Case Diagram

Through ‘Morning Walk S200’, users can experience various VR game contents to enhance the effectiveness of rehabilitation therapy. Fig. 3 is a diagram of the use cases and requirements of these users. It is a simple summary of the requirements that may arise between professionals and patients who assist in rehabilitation training.

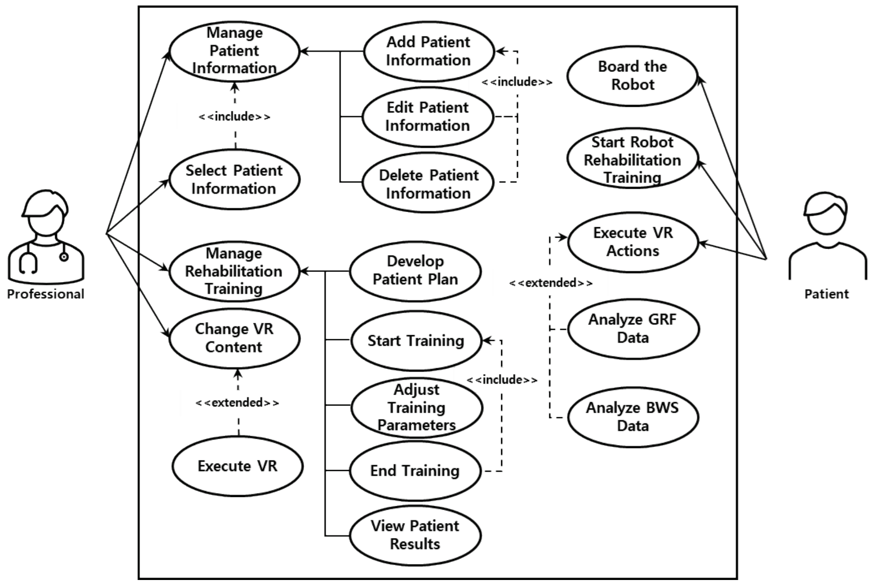

Figure 3 Use case diagram: user requirements

Figure 4 Morning Walk S200

The therapist conducts four requirements (Fig. 3): Manage patient information, select patient information, manage training, and change VR content. The therapist can *Add/Edit/Delete Patient Information* by himself. They can also *Plan/Start/Adjust the Parameters*, End the Training, and *View Results* for further *Training Management*. The patient executes three requirements: *Boarding the robot, training the robot, and Participating the VR events*. By boarding the robot, the patient provides GRF (Ground Reaction Force) and BWS (Body Weight Support) data to the robot. Then, the robot passes the information to the VR content, and the VR content analyses the data. Lastly, based on the analyzed results, the VR content events implement.

3.3 Morning Walk S200

Morning Walk provides a real-time monitoring and biofeedback system. You can check joint angle values for hip, knee, and ankle in real time [7, 14]. You can also monitor GRF, BWS, plantar pressure distribution, and balance through the Butterfly Diagram [7].

Fig. 4 is ‘Morning Walk S200’, a robotic orthotic exercise device and walking rehabilitation robot developed by Curexo. It is a compound word of Morning + Walk which signifies the meaning of presenting (rewarding) a comfortable morning walk [6]. It is a medical robot developed to help patients with walking difficulties recover and provides optimized training for children and adults [19, 21]

There are two types of lower limb rehabilitation robots: the exoskeleton type, which is worn directly on the patient's body, and the end effector type, which simply connects the end of the device to the patient. ‘Morning Walk S200’ is an end effector type, which means it has a high degree of freedom in the movement of the center of gravity, unlike the exoskeleton type, which limits the range of motion of the center of gravity during gait training. End-effector-type walking robots are more suited and safer for various neurological diseases [8, 18]. Gait training with Morning Walk S200 has been proven to improve mobility and balance in subacute and hemiplegic patients [9, 16, 17], and the scaffold-based gait component has been proven to be a valid rehabilitation method for lower extremity movement [10, 15, 20, 26].

4 VR CONTENT ON THE MORNING WALK S200

Fig. 5 shows the VR contents that are officially supported by Morning Walk S200. We currently support five VR content and are continuously conducting content research and development. The VR content utilizes the trainer's foot pressure and BWS values to generate events and interact with the user. The VR content we currently support was created based on ideas developed internally at Curexo in collaboration with VR development companies.

Figure 5 Morning Walk S200 - officially supported VR content

Figure 6 Morning Walk S200 - training with an HMD

As shown in Fig. 6, the patient checks the VR content on the front screen after boarding the Morning Walk. The VR content is linked to ‘Morning Walk S200’ and receives data input in real-time. Each VR content has a 'Foot Calibration' function, which analyzes the patient's average foot pressure and sets that value as the default value. The foot pressure value is then read in real-time and used to trigger events in each content.

Character movement in certain VR content can be set to behave normally when the patient's foot pressure is higher than the average foot pressure. The patient actively participates in the training to activate the normal behavior of the VR content character. In addition, there are events such as eating items in the content map and completing timely events to enhance the patient's interest. We are researching various events to actively engage patients. Morning Walks are conducted after wearing the HMD. However, patients who are not familiar with 3D content may experience discomforts such as motion sickness, so it is used selectively. Rehabilitation training is conducted through 360° VR content when wearing an HMD. The screen that the patient wearing the HMD sees is simultaneously transmitted in real-time to the TV in front of the Morning Walk equipment.

Patients who have difficulty performing normal movements can adjust the level of training by lowering the level of abnormal gait or adjusting the robot's movement speed in the VR content settings. Fig. 7 is a VR content that depicts the Saryeoni Forest in Jeju Island. It is possible to enjoy the scenery without any specific events, so even patients with difficulty walking can enjoy VR content. The map progresses in the following order: Rain Forest, Pine tree, Redwood, Valley, Flower field, Winding path, Waterfall, or Lake. When you first start, you can specify where you want to start and progress through the training.

Figure 7 Morning Walk VR - Saryeoni Forest, Jeju Island

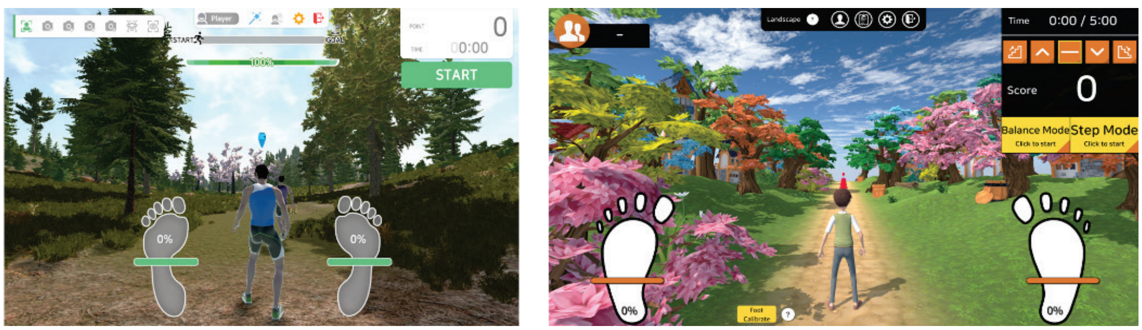

Figure 8 Morning Walk VR - Landscape

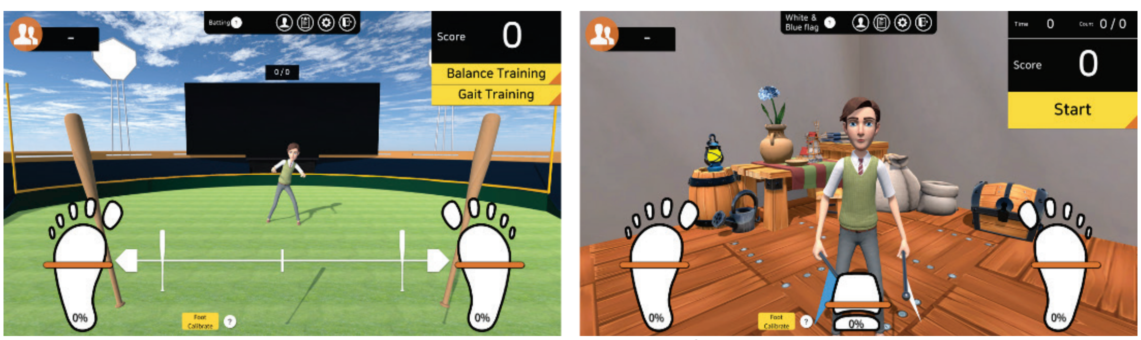

Figure 9 Morning Walk VR - Activity Game

Fig. 8 is the Morning Walk VR content 'Landscape'. Morning Walk has a total of five protocols (Over Ground, Stair Up, Stair Down, Slope Up, Slope Down). The VR content automatically changes to the appropriate terrain for the protocol when the protocol is changed. The patient gets the feeling that they are actually performing the protocol in the robot's behavior as the appropriate terrain appears. Stair Up/Down provides the ability to adjust the stair height value and Slope Up/Down provides the ability to adjust the slope angle value, providing a wide range of training protocols for patients.

Fig. 9 is an Activity Game from Morning Walk. On the left is a baseball game, and on the right is a blue-and-white flag game. The baseball game tells you when the ball will fly during the exercise, and if you step on the footstep at the right time, you will hit the ball. In Blue and White Flag, you will see phrases like "Blue Flag up - Blue Flag down" and "White Flag up - White Flag down" on the screen. If the player performs the command within a certain amount of time after the phrase appears, they will succeed. Active games help patients focus on their rehabilitation training. Unlike other games, the Blue-White Flag game has a saddle event: sit/stand up.

Depending on the patient's severity level, the intensity, duration, and number of exercises vary. Each VR content repeats a unique event without any specific reward, such as giving items to customize the character or providing in-game currency to purchase specific items. In this case, patients who are training for an extended period may feel bored with the VR content. Therefore, in order to provide a variety of VR content, Curexo is developing its own VR content as well as holding VR content planning contests.

Figure 10 Winners of the Morning Walk VR game content planning contest

Fig. 10 is the winner of the first Morning Walk VR game content planning contest. Through the content planning contest, we got various ideas such as a game that catches grapes falling from the sky in a bowl, a skiing game, and a painting game. A total of forty-five teams participated in the contest, and eight teams were selected to receive awards. These ideas will be utilized for future Morning Walk VR content development.

5 CONCLUSION AND FUTURE RESEARCH

The "Morning Walk S200" is a walking rehabilitation robot developed by Curexo, designed as an end-effector type. It features a weight-bearing seat, a footrest for walking exercises, real-time monitoring, biofeedback, and the provision of virtual reality (VR) content. The VR content aims to engage patients actively in their training and enhance their interest in therapy. In this paper, we introduce the "Morning Walk S200" and discuss the utilization of VR as a key technological element in digital therapies for rehabilitation.

As the aging society accelerates around the world and the elderly population increases, the number of falling accidents, cognitive dissonance, and various chronic diseases is increasing. Thus, hospitals and several research institutes are developing various rehabilitation treatment devices that combine IT technology and Rehabilitation robots, and many researchers have established to prove the effectiveness of these treatments [27 - 29]. Furthermore, as the market develops for contents installed in treatment devices, it creates greater benefits that could increase treatment effects [30 - 34]. Hence, we hope this paper will be used as future reference research material to follow when developing digital healthcare industry content.

Based on this study, we set three future research directions. First, research on design techniques for VR content in rehabilitation therapy. As the purpose of utilizing VR content is to improve patients' willingness to actively participate in rehabilitation training and enhance their interest in treatment, the content should not be complex or colorful to lose its main purpose. Therefore, we would like to conduct a study on how to design VR content that can enhance patients' active participation in training and interest in treatment without losing the main purpose of rehabilitation training.

Second, we will study how to design XR content optimized for rehabilitation therapy. Patients undergoing rehabilitation therapy board a morning walker and train while looking only at the VR content on the monitor. It is believed that providing an XR world rather than just a VR world will allow patients to participate more actively in rehabilitation and increase their interest in treatment than VR alone. Therefore, we would like to conduct research on XR content design techniques optimized for general-purpose gait rehabilitation training.

Third, we need to create a formal evaluation method for VR or XR content. Currently, the experience of using Morning Walk's VR content is only conveyed verbally to patients and therapists. Without a structured evaluation method in place, it is challenging to enhance the quality of the content. Therefore, we propose conducting a study to develop a structured evaluation method for VR or XR content, which will help us design content optimized for rehabilitation therapy.

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