Integration of Augmented Reality with Pressing Evaluation and Training System for Finger Force Training

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Abstract. One major concern for the elderly is the decline in their ability to control their hands, which can significantly affect their ability to perform activities of daily living. One of the important hand functions that deteriorate over time is the ability to control finger force exertion, due to the gradual decrease in finger muscle strength as people age. Previous studies have shown that with proper training, it is possible to regain finger strength. However, when designing training systems for finger force control, visualization of the finger forces plays an important role in its effectiveness. In this paper, we describe the development of the augmented reality pressing and evaluation system (AR-PETS), an augmented reality based prototype system for finger force control training. We discuss the development of the system, as well as the design considerations during the development of the system.

Keywords: Augmented reality · Finger force training · Gamification · Pressing evaluation and training system

1 Introduction

People experience a decline in their capability to control different parts of their bodies as they age. One major cause for concern for the elderly is the decline in their ability to control their hands, which can manifest in the form of reduced finger dexterity, strength, coordination and sensation [1,2]. This can significantly affect their capability to perform activities of daily living (ADLs) that require precise control of their fingers, such as grasping and picking up items.

However, studies have shown that with proper training, regaining control of the hands to a certain extent is possible [3–6], thus enabling the elderly to recover their ability to perform ADLs. Because of this, various training programs for different aspects of hand control have been devised to assist the elderly.

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One particular training that they perform is finger strength training, wherein the tasks usually involve controlling and sustaining the amount of force they exert with their fingers over a period of time. To ensure accurate finger force production, proper feedback is necessary, and previous studies have shown that the lack of feedback during finger strength training can have a negative impact in force control ability [7–9].

Considering the medium for displaying the visualizations representing the finger forces is also important. Usually, training systems display visualizations with a monitor. However, this results in divided attention to two different places, potentially increasing cognitive load. In recent years, augmented reality (AR) technology is re-surfacing as a way of displaying virtual information. AR provides us with the ability to superimpose virtual objects onto the real world, enhancing our perception of and interaction with the real world [10]. In the context of training, we can potentially reduce the cognitive load placed onto the user by placing the finger force visualizations directly on top of the fingers. This allows users to see their hand together with the visualizations, making it easier for them to map a finger with its corresponding visualization.

Based on the above considerations, we developed AR-PETS, a system for finger strength training that integrates augmented reality with the pressing evaluation and training system (PETS), a device specifically built for measuring finger force. In this paper, we discuss the different components of the system, as well as the design considerations during the development of the system.

2 Related Work

2.1 Traditional Hand Rehabilitation Methods

Traditional methods for training hand functions usually involve training with a device specifically built for hand training. For example, a study by Olafsdottir et al. [4] used a hand training device (Digi-Flex) to administer finger strength training to elderly participants. The device can be set to generate different levels of force resistance, and participants train by squeezing the device with their fingers through different levels of resistance. Parikh and Cole [11] asked participants to perform tasks that involve picking up a custom-built object and moving it to different positions and orientations. The custom-built object contains force sensors that measure the force exerted by the participants while grasping the object, and was used as a way to evaluate hand strength and dexterity. One common limitation of these traditional methods is the lack of real-time feedback regarding their performance during the training, e.g., the correctness of their motion, or the amount of force they are exerting with their fingers. Previous studies have shown that the lack of real-time feedback during training can lead to a slow decline in their performance during training, especially in tasks involving accurate finger force production [7–9].

2.2 Multimodal Approach to Hand Rehabilitation Feedback

To address this problem in traditional methods for training hand functions, current systems utilize different modalities to convey a variety of information in real time during training. For example, there are training systems that use auditory displays to convey information to the trainees. Wallis et al. [12] encoded arm movement information into musical notes, and administered training by asking the trainees to move their arms in such a way that they produce pleasing music. Järveläinen et al. [13] encoded finger force into note pitch, and instructed trainees to associate the pitch of the note that they hear and the amount of force they are exerting with their finger.

Training systems commonly present feedback visually, using different forms of media. For example, the systems introduced in [7–9,14,15] use monitors to display visual feedback regarding the amount of force exerted by the trainees onto a force measurement device. Taheri et al. [16,17] and Friedman et al. [18] developed gamified training systems that display both visual and audio feedback for finger movement training. Immersive virtual reality (VR) is also being used for training, where trainees are immersed in a completely virtual environment to make the training tasks more engaging. For example, immersive VR games were developed to promote engagement when undergoing rehabilitation for upper limb movement, such as those done by Elor et al. [19] and Baldominos et al. [20].

2.3 Augmented Reality in Hand Rehabilitation

In recent years, augmented and mixed reality is also being used in rehabilitation programs to enhance motivation and enjoyment of patients while undergoing training. Luo et al. [21] integrated augmented reality with special gloves designed for hand opening rehabilitation to display virtual objects for reach-and-grasp task training. They conducted a preliminary study with three participants, and found general improvements in patients' performance during standard functional tests. Burke et al. [22] described the design principles for creating AR games for rehabilitation, and developed various examples of AR games for rehabilitation using those design principles. Hondori et al. [23] investigated the impact of interface choice on patients' performance during rehabilitation for hand and arm movement. They developed a desktop and projector-based AR version of a popular game "Fruit Ninja" to be used for rehabilitation, and evaluated how patients performed for each version. They found that patients generally had faster reaction times and more targeted movement in the AR version as opposed to the desktop version. They attribute these results to higher cognitive demand for the desktop version since patients need to consider hand-eye coordination. Colomer et al. [24] described the use of a mixed-reality tabletop system as a rehabilitation tool for upper limb rehabilitation. The system presented the users with different mini-games that require the use of different kinds of arm and hand movements to complete. They recruited 30 participants who are recovering from stroke, and found significant improvements in their performance after the training.

They also reported that the system had a positive effect on participants' enjoyment and motivation towards the training.

While the aforementioned systems utilized augmented reality for hand rehabilitation, they focus more on hand and finger movement training, rather than training for accurate finger force production. The closest work with this current study is done by Plopski et al. [25], who developed the original idea of AR-PETS. In their study, they used a haptic device as a substitute for a PETS device to measure finger force, and a video-see-through head-mounted display to display the force visualizations next to the trainees' fingers through augmented reality. They conducted a user study with 18 students, and while they found no significant improvement in performance due to AR, participants expressed their preferences towards AR. The current study extends the training system developed in the previous study by replacing the AR display from a video-see-through head-mounted display to an optical-see-through head-mounted display (Microsoft HoloLens [26]), and by using an actual PETS for the training.

3 AR-PETS Prototype

3.1 System Overview

Figure 1 shows a diagram of how AR-PETS generally work. From this point on, we will refer to the person undergoing the training as the "trainee", while the person administering the training as the "trainer". The trainee, who is wearing the HoloLens, exerts force onto the PETS, which is captured by the PETS as voltage signal. The voltage signal is then sent to the computer, where it will be sampled and filtered. The sampled data is then sent to the HoloLens, which updates and renders the force visualizations back to the trainee.

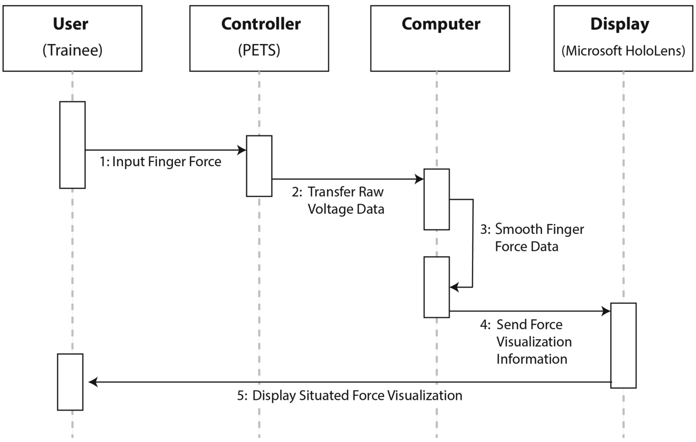

Fig. 1. Overview of AR-PETS.

The AR-PETS consists of the following components: the PETS that measures the finger forces, a software for acquiring and processing raw data from the PETS, a control panel application for controlling parameters related to the training, and a HoloLens application that displays the training program on top of the real-world using the AR capabilities of the HoloLens. Figure 1 shows a diagram describing the prototype system.

Pressing Evaluation and Training System. PETS is a device for measuring the amount of force exerted by a person's fingers through the 5 force plates that are built into the device (Fig. 2). Trainees rest their hand on the device such that all five fingers are touching the force plates, and they press down the force plates with their fingers to exert the specified amount of forces during the training. The position and height of each force plate can all be adjusted as necessary to fit the trainee's hand. The configuration of the force plates can also be rearranged to support training for both left and right hands.

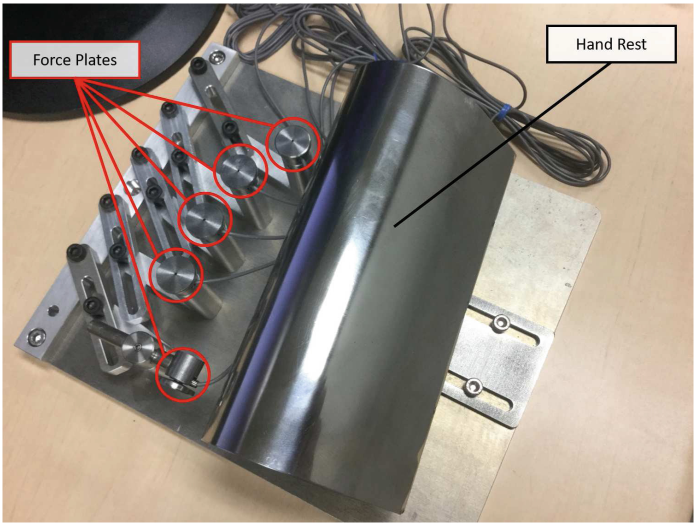

Fig. 2. Pressing evaluation and training system.

Data Acquisition and Processing Application. A data acquisition application based on LabWindows/CVI [27] acquires raw force data measured by the PETS. Upon receiving new data from PETS, the application attempts to reduce noise from the data using a simple moving average filter, where it takes the average of the last 5 samples. The resulting filtered data is then delivered via the UDP networking protocol for external programs to use and process. In the case of AR-PETS, the data is sent locally to a separate application that manages the training program itself.

Training Control Panel Application. The training control panel application based on Unity [28] provides a user interface for controlling the training program. The application allows the trainer to choose from different training modes for the trainees to perform, and to adjust different parameters related to the training modes. A detailed description of the different training modes can be found in Sect. 4.2. The application also shows a representation of the trainee's progress through the training mode.

HoloLens Application. The HoloLens application is a separate Unity-based application that displays the different virtual information needed for the training to the trainee wearing the HoloLens. The HoloLens application receives different commands from the training control panel application, and updates the virtual information that the trainee sees accordingly.

3.2 Calibration

Position Calibration. One of the main advantages of AR is the ability to superimpose virtual information on top of the real world in such a way that the virtual information appears to be integrated with the real world. To do so, the AR system requires a specific location in the real world to overlay the information onto. Thus, for this application, we perform a manual calibration procedure to provide the HoloLens application with real world position information of the finger force plates. This allows the HoloLens application to accurately place the corresponding visualization for each finger. The calibration procedure consists of positioning an AR marker on the location of each finger force plate, then letting the HoloLens detect the marker using its front camera and the Vuforia AR library (Fig. 3). We created a 3D-printed stand for the AR marker for this purpose. We repeat this procedure for all 5 fingers. After calibrating all 5 finger positions, the HoloLens saves these position data internally. This allows the HoloLens to reuse the positions across sessions, eliminating the need to calibrate every time, assuming that the PETS device is not moved.

Maximum Force Calibration. Different people have different amounts of maximum force that they can exert with each finger, also known as the maximum voluntary contraction (MVC). Thus, this prototype system also provides a calibration routine to measure the MVC of each user. During calibration, we ask trainees to exert as much force as possible for each finger, one finger at a time. Upon completion, the measured maximum forces can now be used as a basis for the different training modes, which are described in the next section.

4 AR-PETS Training

In this section, we first describe the different finger training patterns that we used as basis for designing the training modes. We then follow this with a description of the different training modes that the AR-PETS can possibly provide.

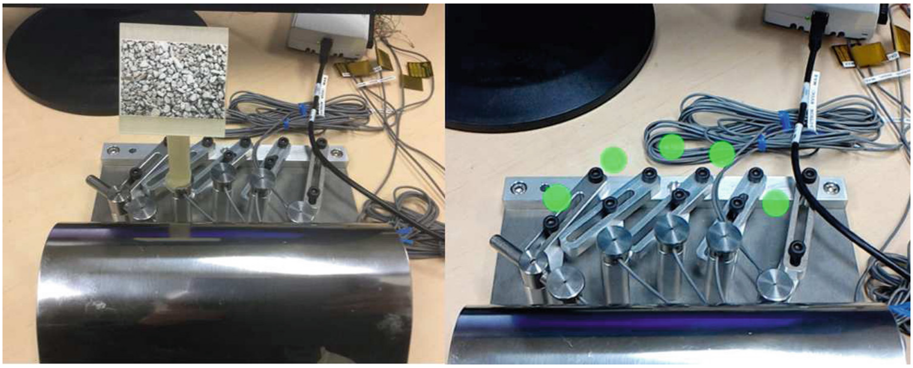

Fig. 3. Position calibration using an AR marker attached to a stand (left). The calibrated positions of the finger force plates are then visualized after the calibration procedure (right).

4.1 Finger Pressing Patterns

The hand is capable of performing different kinds of force exertions, e.g., single and multiple digit exertions [29]. Based on this idea, we considered 4 patterns for finger force training, namely: single digit pressing, synchronous pressing, rhythmical pressing, and pressing with force variation. Figure 4 provides a summary of these 4 training patterns. In single digit pressing, the trainee presses down the force plates with a predetermined force one finger at a time. This pattern enforces the trainee to sustain the force they exert with one finger. In synchronous pressing, the trainee presses with two or more fingers at the same time, also with a predetermined amount of force for each finger. The goal for this is to sustain the force they exert with multiple fingers at a time. In rhythmical pressing, the trainee presses with their fingers in a certain rhythm, which trains the trainee's ability to control fingers at will, and as well as stamina. Finally, force variation makes the trainee's fingers press the force plates with varying amounts of force over time, which trains the control of the amount of force exerted with the fingers over time. These 4 training patterns become the basis for designing the training modes in AR-PETS, which will be described in the next section.

4.2 Training Modes

AR-PETS offers four training modes for the trainees to choose from, namely: sequential force pressing, dynamic force tracking, rhythm game, and obstacle avoidance game. Each training mode implements one or more of the finger force training patterns outlined in the previous chapter. For the modes regarding games, we refer to the trainee as the player. The following sections describe each training mode in more detail.

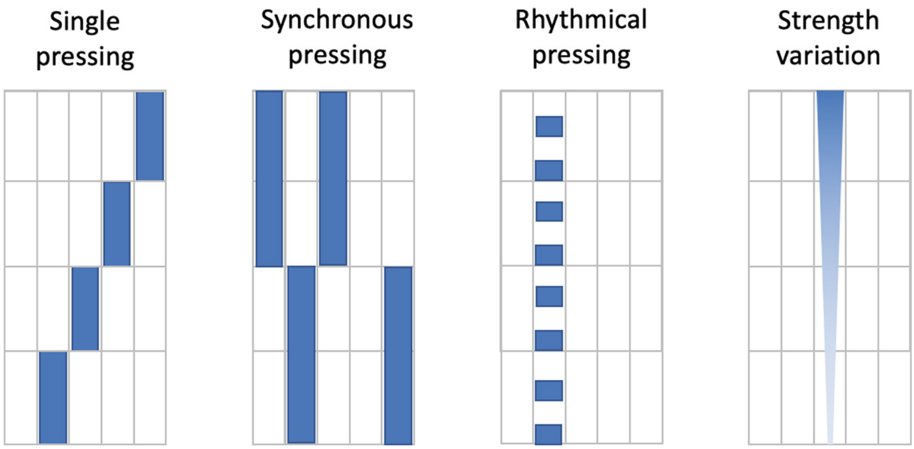

Fig. 4. The 4 training patterns for finger force training.

Sequential Force Pressing. In this mode, we ask the trainee to exert a certain amount of force for each finger, and sustain it for a certain amount of time. The trainee performs the task one finger at a time, in a specific order. This training mode implements the single digit pressing training pattern, and is geared towards training the ability to maintain the force exerted by each individual finger within a certain duration.

While wearing the HoloLens, this mode presents trainees with 5 bar graphs (one for each finger) that are rendered on top of the finger force plates. The bar graphs show the amount of force they are exerting with each finger, and also the amount of force they need to exert for each finger. The trainee must fill up the bar graph and reach the target force. The target force for each finger is based on percentages of the MVC for each finger, which can be set by the trainer via the training control panel application. Finally, an indicator displayed on top of the bar graphs notifies the trainee which finger to press, and this indicator moves through each finger in a specific order, which can also be set via the control panel application.

Dynamic Force Tracking. In this mode, the trainee is asked to exert variable amounts of force with their fingers over time, either with a single finger or a combination of fingers. This training mode implements the single pressing, synchronous pressing, and force variation training patterns, and is designed for training the trainee's ability to dynamically adjust the amount of force they exert with their fingers (Fig. 5).

With the HoloLens, the trainee is presented with a line graph, with the x- and y-axis representing time and force respectively. The graph contains a red line representing the force that the trainee is exerting, as well as a green line representing the amount of force needed to be exerted over time (Fig. 6). The trainee should match the green line as closely as possible by exerting the

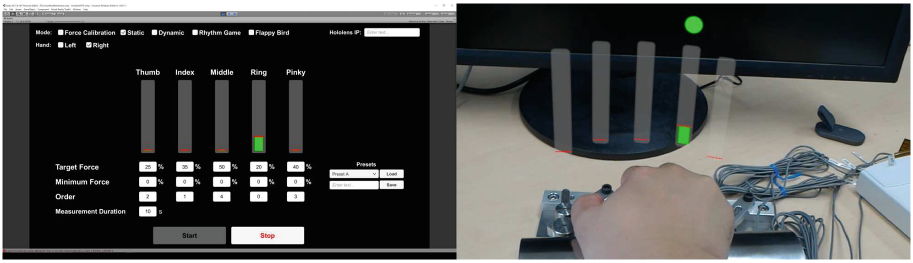

Fig. 5. Trainer's view (left) and trainee's view (right) of the sequential force pressing training mode.

necessary amount of force with the specified finger/s, which are indicated with green circles rendered on top of the fingers. The fingers the trainee needs to use can be specified by the trainer using the desktop control panel application.

The target force line consists of five phases: resting phase, rising phase, plateau phase, falling phase, and another resting phase. The initial resting phase serves as the time for the trainee to prepare, while the later resting phase signals the end of the session. The plateau phase represents the maximum force that the trainee needs to exert for that session, and is decided based on a percentage of the MVC (or the sum of MVCs) of the specified finger/s. The rising phase requires the trainee to gradually increase the force until they reach the plateau phase, and the falling phase requires the trainee to gradually decrease the force until the resting phase. The amount of time the trainee spends on each phase can also be controlled using the desktop control panel application.

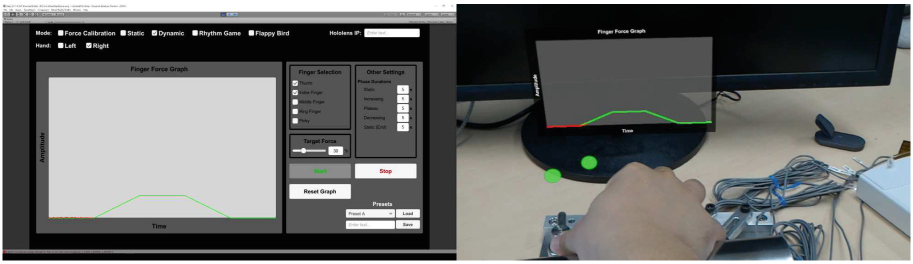

Fig. 6. Trainer's view (left) and trainee's view (right) of the dynamic force tracking training mode. (Color figure online)

Music Game. Previous studies have shown that incorporating music games into rehabilitation programs can increase the motivation of rehabilitation patients to undergo the training [18]. With this in mind, we added a training mode that incorporates music game mechanics. In this mode, players must press with their fingers in time with a music (Fig. 7). Musical notes descend onto each finger's position, giving an indication to the player of which fingers to press. The height of musical notes determines how long the player must press with the finger, and the width determines how much force is needed to exert for the corresponding finger, which can either be constant or varying throughout the duration of the note. This training mode implements all of the training patterns.

Song selection is possible through the training control panel application. This allows the trainee to choose songs that they like, potentially enhancing their motivation to go through the training. The difficulty of the song can also be adjusted by modifying the music score for that song, e.g., by introducing different note patterns such as double notes or notes that vary in force over time, or by introducing big variations in terms of the target force between each note.

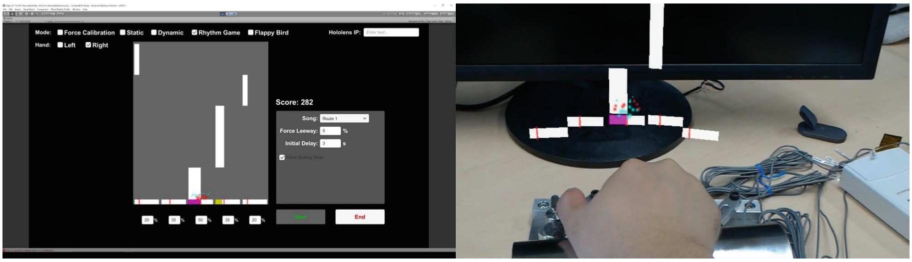

Fig. 7. Trainer's view (left) and trainee's view (right) of the music game training mode.

Obstacle Avoidance Game. In this mode, the trainee as a player plays a rendition of the game "Flappy Bird" [30], where the goal is to guide an avatar to avoid as many obstacles as possible (Fig. 8). The player controls an avatar that automatically scrolls to the right, while avoiding obstacles that appear in certain time periods as they scroll to the left. The obstacles consist of two pillars (top and bottom) with a gap in between, and the player needs to guide the avatar through these gaps. When the avatar touches the pillars, the game ends and the player is given the option to start over. Since the avatar automatically moves from left to right, the player can only control the vertical position of the avatar, which is done by pressing with the designated fingers. The vertical position of the avatar is based on the amount of force relative to the sum of the MVCs of the designated fingers. When no force is exerted, the avatar is positioned in the lower bound of the game area. Exerting 50% of the sum of MVCs puts the avatar in the middle, and exerting 100% of the sum of MVCs puts the avatar in the upper bound of the game area, which also results in game over.

The difficulty adjustment of the game is also possible through the training control panel application, as certain parameters can be modified to affect how the obstacles are generated or spawned. One such parameter is the time between two obstacle spawns. A shorter time between obstacle spawns means that the obstacles are closer to each other, requiring the user to adjust the force quickly, while a longer time between obstacle spawns means the obstacles are farther away from each other, giving the player more time to adjust the force they are exerting. Another parameter is the height of the gap of the obstacles. A smaller gap for the obstacles requires the player to be more precise with the force they exert, while a larger gap gives more leeway for the player.

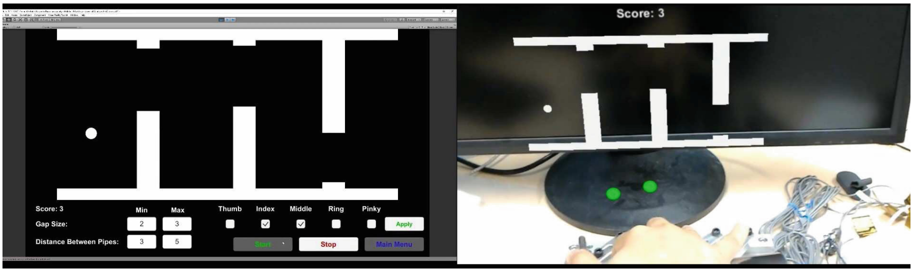

Fig. 8. Trainer's view (left) and trainee's view (right) of the obstacle avoidance training mode.

5 Conclusion and Future Work

In this paper, we introduced AR-PETS, a prototype system that integrates augmented reality and the pressing evaluation and training system to facilitate finger force control training. We hypothesize that using augmented reality as a medium to present the training environment has the potential to reduce the cognitive load of patients undergoing the training by rendering important information about the training directly on top of their fingers. We described the different components that make up the system, the different types of finger force training methods that we considered, and the four training modes included in the system, namely sequential force pressing, dynamic force tracking, music game, and obstacle avoidance game.

We have yet to conduct a formal user study to evaluate the effectiveness of the system for finger force training. However, we plan to further improve the prototype system and eventually conduct a user study to evaluate whether incorporating augmented reality into finger force training can effectively reduce cognitive load of elderly people undergoing rehabilitation, and how the presentation of the different training modes can have an impact on their performance and motivation over time.

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