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RehaBricks: An Electronic Modular Pegboard for Improving Upper Limb Exercise Adaptability

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***Abstract*—Pegboards are commonly used in occupational therapy for upper limb rehabilitation. However, conventional pegboards do not allow for automatic tracking of training sessions. Additionally, although several electronic pegboards are currently available, they are all limited in the set of rehabilitation exercises that can be executed, due to their fixed planar shape. To address this issue, we introduce a novel electronic modular pegboard system, Rehabricks, which is composed of basic module units and can be assembled into curved shapes. By offering more complex patterns and shapes, Rehabricks can provide more adaptable exercise arrangements, suitable for each patient's needs. Experimental results suggested that Rehabricks can be used to stimulate more rotational movements than conventional pegboards, while also creating a more fun and engaging experience.**

***Index Terms*—Upper Limb Rehabilitation, Electronic Pegboard, Rehabilitation Exercise**

I. Introduction

Conventional physical rehabilitation is performed with the help of standard sets of physical objects that must be manipulated by patients in other to stimulate brain paths and improve their ability to perform specific functions [1]. In particular, pegboard tests, e.g. the Purdue Pegboard Test [2], [3], the Nine-Hole Peg Test [4] and the Box and Block test [5], [6], are widely used for upper limb rehabilitation. For pegboard tests, traditional analogue pegboards allow patients to execute a range of exercises that involve holding and inserting a set of pegs into the correct holes following specific rules and time limits. However, tracking of exercise accuracy and timing must be done manually by the therapist through visual observation and individual evaluation.

Recently with the development of electronic pegboards, it has become possible to dynamically generate different training patterns and to also collect patient performance data that can support treatment planning [7]. Electronic pegboards also show potentials for fused rehabilitation of hand manipulation and attention/executive function at various difficulty levels [8]. On the other hand, although a few commercial electronic pegboards have been developed, there are still limitations that restrict the type of rehabilitation exercise that could be executed, including: the size of the board is fixed; all boards consist of a planar structure, with no possibility of exploring different angles for the pegs; and there is only a small set of colors that can be used to define patterns.

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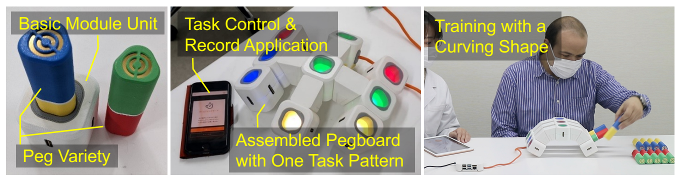

(a) (b) (c)

Fig. 1. Images showing the concepts of our RehaBricks system including (a) a single module unit with pegs of different colors, (b) a convexly assembled RehaBricks board, with a colored pattern monitored by a smartphone application, and (c) a patient who is exercising with the convex board.

In this paper, we introduce a novel electronic pegboard, referred to as **RehaBricks**, that employs a modularized design to create flexibility both in physical structure and in training variety, widening the range of rehabilitation exercises that can be performed and ultimately improving the therapeutic process both for patients and for medical professionals.

II. System Components

Figure 2 shows the key features of our RehaBricks system. The system is composed of a set of cubic modules that can be connected directly side by side or with a curved piece that changes the angle between the sides.

A. Module Unit

Figure 2(a) shows a module unit which is the basic unit of RehaBricks. On each side of a module there are strong magnets embedded, with opposite polarities (N/S) assigned to adjacent sides as shown in Fig. 2(b). Modules can be connected on any side, as long as the N/S alignment between the connecting sides of each module is respected. A combination of male/female spring-loaded connectors is used in the connection point to establish a stable electrical signal between the modules. Each module also has an LED-illuminated peg hole, with configurable colors in three channels, and a speaker that can emit monotonic sound sequences. The base of the hole

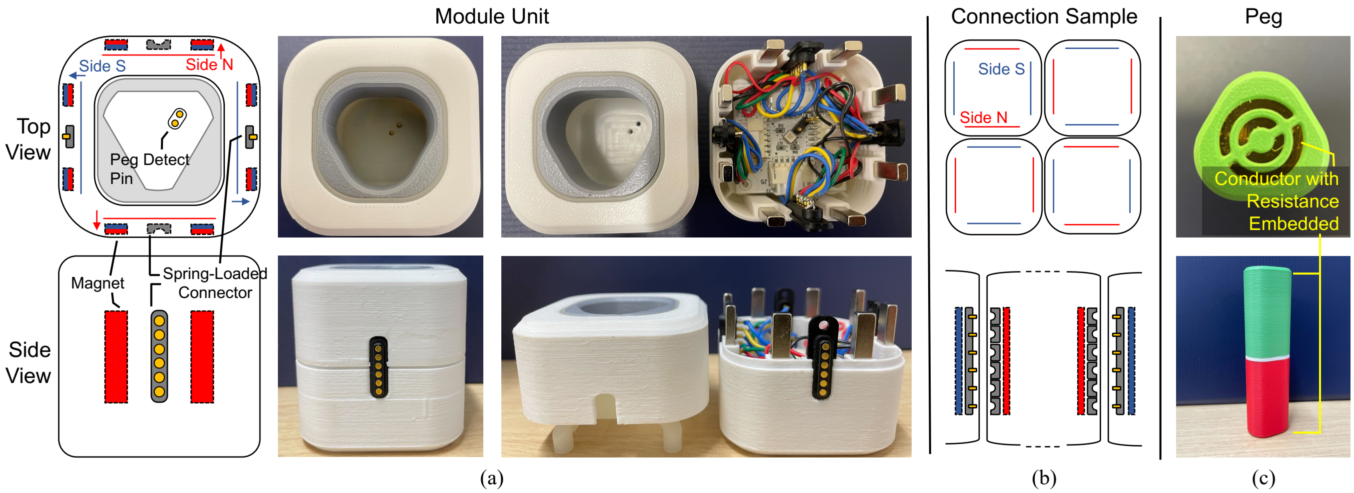

Fig. 2. Pictures and illustrated descriptions of the components and concept of our RehaBricks system. (a) Key features of the basic module unit. (b) Male/female spring-loaded connectors and magnets of opposite polarities are assigned to each side for geometric and electrical connection. (c) The peg has has a halo-like conductor and resistance embedded in each side, allowing for detection of various pegs regardless of the shape of the peg hole and the orientation of the peg. We are not showing the specific measurements of each unit as the size is theoretically flexible, only limited by the size of the embedded circuit board.

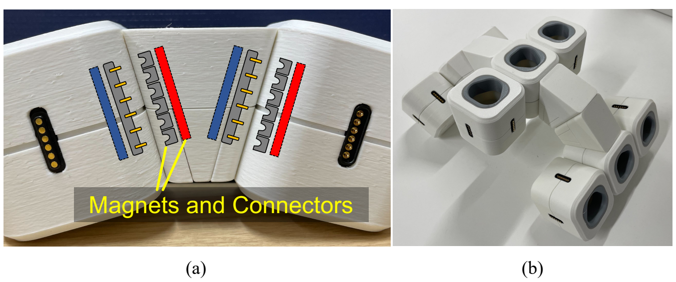

Fig. 3. Pictures showing (a) the curved piece which has magnets and spring-loaded connectors embedded, and (b) a convexly assembled board pattern using four curved pieces.

has a connector that runs a small electrical signal through the peg when it is connected to detect its electrical resistance.

B. Controller Unit

A controller is geometrically similar to a module unit except that it is connected to a microcomputer. The controller unit centralizes the power source and communication bus, and is responsible for detecting the network architecture and setting the state of all modules. The controller constantly scans for new modules and automatically detects and assigns addresses to newly connected modules, while also capturing the overall geometry of the board. The module state information is logged every 500 milliseconds, which allows for an accurate tracking of each exercise during training sessions. An HTTP interface is provided, so it can receive requests from possible clients, such as a smartphone application that sets patterns and captures training session data.

C. Peg

As shown in Fig. 2(c), each side of the peg has a conductor with resistance embedded, and is assigned with its own electrical resistance value. Such novel design has two major advantages: (a) the halo-like shape of the conductor allows for the peg detection regardless of the shape of the peg hole and how the user inserts the peg, and (b) this vastly improves over previously available solutions which rely on magnetic polarity to differentiate pegs and, thus, only offer two types of pegs [8]. Additionally, since the peg halves can be disassembled and freely combined, the same peg can have more than one color and fewer pegs are necessary, which also allows for more complex exercises.

D. Curved Piece

A curved piece is an physical and electrical adapter aimed to enable concave/convex structures between modules. As shown in Fig. 3(a), the curved piece follows the same concept of the module unit where opposite polarities (N/S) are assigned to each side for stabilizing physical connections. The spring-loaded connectors are also embedded in the connection point to establish stable electrical signals.

III. Experiment and Results

To test RehaBricks, we set up an experiment in which we analyzed the user's upper limb movements with our system against that with a conventional pegboard. The experiment is approved by the Ethics Committee of Kyoto University Graduate School and Faculty of Medicine.

A. Protocol

Participants were seated in a non-swivel chair, with the pegboard being placed approximately 30 centimeters horizontally away on the table. After an oral instruction on the tasks, participants were asked to rest their hands on the table in a natural way. Following the concept of the Nine-Hole Peg Test [9], the basic task of the experiment was to insert nine pegs into the pegboard for each trial. While the target holes were directly informed on the board, there was no specific

(a) (b) (c)

Fig. 4. Images showing (a) the experiment setup with the target upper limbs and movements, (b) a sample picture of the actual experiment scene with the participant's motion being tracked, and (c) the four pegboard conditions used for the experiment.

requirement for the inserting order. The tasks consisted of four pegboard conditions for comparison:

- Flat Conventional Pegboard (**Conv_F**)
- Slant Conventional Pegboard (**Conv_S**)
- Flat RehaBricks (**RB_F**)
- Convex RehaBricks (**RB_C**)

as shown in Fig. 4(c). For each trial, following the experimenter's sign, participants were asked to insert nine pegs in total to the designated spots on the pegboard only using their right hand. For each participant, the order of the pegboard conditions were counter-balanced using the Latin square method.

B. Metrics

To evaluate how RahaBricks would change the user's movements, we captured the user's three-dimensional (3D) skeleton and motion data, and analyze the movements of the right upper arm and forearm. The 3D joint points were estimated and obtained using a pre-trained model of VideoPose [10] in MMPose [11] from images captured by an RGB camera.

Specifically, we calculated the vector from the shoulder to the elbow joint as the right upper arm, and the vector from elbow to the wrist joint as right forearm. While simple movements of the upper limb arms can be analyzed separately as flexion/extension, internal/external rotation, and pronation/supination of each joint [12], it is difficult to precisely allocate each rotation to the complex movements such as the pegboard exercise. Thus, we decided to fix the movements to the world Cartesian coordinate and compute the rotation matrix of each vector between frames to describe the rotational movements (Fig. 4 (b)).

In general, the metrics for evaluating the rotational movements in each axis can be interpreted as:

- Longitudinal: The "spinning" movement towards the front from the user's point of view.
- Lateral: The "raising" movement between bottom and top from the user's point of view.
- Perpendicular: The "transforming" movement between left and right from the user's point of view.

C. Participants and Results

The purpose of the experiment is to quantitatively verify how our RehaBricks would change the user's movements. Thus, instead of actual patient, we decided to recruit able-bodied participants who are expected to perform the movements smoothly. Four participants participated in our experiment, with an average age of 28.5 (stdev. 5.26, two female and two male). All participants had no experience in carrying out upper limb rehabilitation therapy.

To evaluate how the upper limb motion varied for different pegboard conditions, for each participant respectively, we cumulatively aggregated the rotational movements of the upper arm and the forearm in each axis (Longitudinal, Lateral, Perpendicular) for each task (Conv_F, Conv_S, RB_F, RB_C) as shown in Fig. 5.

With regard to the upper arm, while a similar movement pattern was observed for all the four pegboard conditions, the RB_C required the most rotational movements in total. Specifically, three of four participants performed huge Lateral and Perpendicular movements in the case of RB_C. With regard to the forearm, huge increase in the Longitudinal and Perpendicular movements for the RB_C condition were observed for all the four participants. It was observed that the participants tended to wrap their forearms hugely in order to insert the peg to the backside of the convex board.

Additionally, all of the participants also insisted that while it was more difficult to complete the task, they had more fun with the convex RehaBricks board.

IV. Discussion

The modularized design of RehaBricks presents many advantages over conditional solutions. First, the possibility of using the curved pieces between module units allows the creation of three-dimensional curves. The experiment results showed that users tend to use more rotational movements on performing tasks with the convexly assembled RehaBricks. It is implied that such design is especially useful for providing exercise tasks that stimulate the flexion/extension, internal/external rotation, and pronation/supination of the upper limb more than the conventional planar pegboards.

Additionally, not only the overall size of the board, but also the arrangement of the peg holes and colors can be customized. This allows the therapist to explore interesting patterns and provide a better spatial arrangement more suitable to the patient's needs or simply more interesting to promote engagement and maintain motivation [13].

Finally, since RehaBricks can be incrementally and dynamically expanded, it is also possible to provide cheaper sets with fewer modules that could be acquired for simpler use cases, such as patients in their own homes, or for more concurrent users in the same clinic. These sets could also be expanded later according to convenience, making our system more cost efficient for the end user.

On the other hand, while RehaBricks has the mechanism to provide visual and auditory feedback to the user, we have not tested its usability and effectiveness from the neuropsychological perspective. We believe that the implemented electronic functionality can enable the exploration of more complex

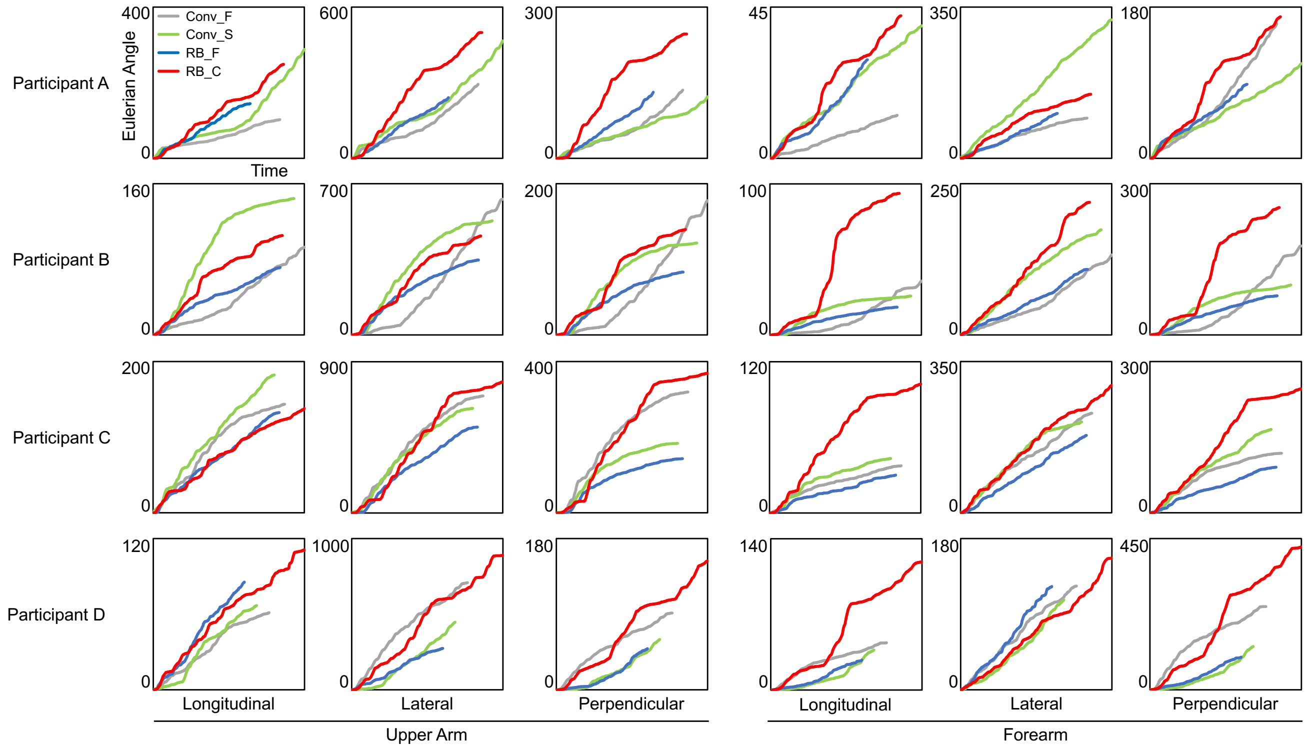

Fig. 5. Line charts showing the over time accumulated rotation of (left) the upper arm and (right) the forearm in Eulerian angle (°). From left to right is the rotation at the three axis, Longitudinal, Lateral, Perpendicular respectively, of world Cartesian coordinate. In the chart, each line stands for each pegboard condition (Conv_F: conventional pegboard flat; Conv_S: conventional pegboard slant; RB_F: RehaBricks flat; RB_C: RehaBricks convex). In short, this figure is aimed to quantitatively show how much the upper arm and the forearm have rotated in total throughout the trial.

patterns and exercise mechanics, which is of our first priority to verify in the future.

V. Conclusions

In this paper, we presented a novel electronic pegboard system, RehaBricks, which is available for providing upper limb rehabilitation exercise that is more flexible. Allowing for three-dimensional assembling and various patterns, RehaBricks is able to improve exercise adaptability by enabling tasks such as a convex board which is not possible for planar boards to stimulate more complex movements from the user. It is expected that this design can improve the effectiveness of rehabilitation for patients, allowing for new types of training exercises that are more adaptable for each patient's needs, while also proving a more fun and engaging experience.

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