Exploring the Impact of an Interactive Electronic Pegboard on Manual Dexterity and Cognitive Skills of Stroke Patients: A Preliminary Analysis

Shih-Ying Chien, Ching-Yi Wu, Alice May-Kuen Wong, Chih-Kuang Chen, Sara L Beckman

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Abstract

Background: As individuals age, the incidence and mortality rates of cerebrovascular accidents significantly rise, leading to fine motor impairments and cognitive deficits that impact daily life. In modern occupational therapy, assessing manual dexterity and cognitive functions typically involves observation of patients interacting with physical objects. However, this pen-and-paper method is not only time-consuming, relying heavily on therapist involvement, but also often inaccurate.

Objective: Digital assessment methods therefore have the potential to increase the accuracy of diagnosis as well as decrease the workload of healthcare professionals.

Methods: This study examines the feasibility of an interactive electronic pegboard for the assessment and rehabilitation of stroke patients. We explored its clinical applicability by examining the relationship among stages, timing, and difficulty settings as well as their alignment with patient capabilities. Ten participants used a prototype of the pegboard for functional and task assessments; questionnaire interviews were conducted simultaneously to collect user feedback.

Results: Results demonstrated that stroke patients consistently required more time to complete tasks than expected, significantly deviating from the initial timeframes. Additionally, the participants exhibited a slight reduction in performance levels in both manual dexterity and cognitive abilities. Insights from questionnaire responses revealed that the majority of participants found the prototype interface easy and enjoyable to use, with good functionality.

Conclusions: This preliminary investigation supports the efficacy of interactive electronic pegboards for the rehabilitation of the hand functions of patients as well as training their attentional and cognitive abilities. This digital technology could potentially alleviate the burden of healthcare workers, positioning it as a valuable and intelligent precision healthcare tool. Clinical Trial: The research protocol underwent rigorous scrutiny and received approval from the Research Ethics Board of Chang Gung Hospital (Reference No: IRB/REC No: 202301197A3).

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Abstract

Background/Purpose: As individuals age, the incidence and mortality rates of cerebrovascular accidents significantly rise, leading to fine motor impairments and cognitive deficits that impact daily life. In modern occupational therapy, assessing manual dexterity and cognitive functions typically involves observation of patients interacting with physical objects. However, this pen-and-paper method is not only time-consuming, relying heavily on therapist involvement, but also often inaccurate. Digital assessment methods therefore have the potential to increase the accuracy of diagnosis as well as decrease the workload of healthcare professionals.

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Keywords: *interactive electronic pegboard; stroke; hand dexterity; cognitive rehabilitation; system*

Introduction

The global population of elderly individuals is likely to continue to increase in the coming decades[1, 2]. The elderly population faces an array of economic, psychological, and societal challenges, as well as increased vulnerability to diverse chronic ailments[3-5]. Among these, hypertension is a critical concern closely associated with the occurrence of strokes[6, 7]. In 2020, 7.08 million individuals succumbed to cerebrovascular disorders [8] and over 12.2 million people are diagnosed with new strokes each year. That means one in four individuals globally over the age of 25 will experience a stroke in their lifetime [7]. Due to continuous advancements in medical technology, the survival rate for stroke patients has reached approximately 62%[9]. However, there is an almost 90% probability that stroke survivors will experience residual effects, which underscores the importance of rehabilitation and occupational therapy[10, 11].

Cerebral stroke, arising from damage to cerebral tissue, induces varied neurological symptoms contingent upon the site of injury. These symptoms often give rise to impairments in motor function, sensory perception, and cognition, which can manifest as diminished attentional focus and memory deficits[12, 13]. These changes in capabilities often entail significant consequences for patients, affecting their daily functioning, occupational status, and social engagement[14].

To enhance the physical mobility, manual skills, and cognitive abilities of stroke patients, physical or occupational therapy is commonly employed in clinical settings as a foundational approach[15-18]. Occupational or physical therapists frequently utilize toys such as building blocks to train patients in hand dexterity, hand-eye coordination, bilateral coordination, visual perception, and attention[19, 20]. In line with this approach, the Nine-Hole Peg Test (NHPT) and the Purdue Pegboard Test (PPT) are commonly utilized for the assessment of manual dexterity[21]. Whether they are employed for assessment or rehabilitation, these activities are routinely conducted in a one-on-one format, and both involve the utilization of a countdown timer to measure the time taken by patients to complete each task. This method has been substantiated in clinical settings as effective for the assessment of attention, cognition, and manual dexterity[22, 23]. The commercially-available Neofect Smart Pegboard is designed to enhance the training process by making it more interesting and interactive using audiovisual features. Upon completion of the training, the device calculates outcomes such as accuracy and the time taken to place pegs. Despite the considerable advancements of the Neofect Smart Pegboard in aiding stroke patients in rehabilitation and cognition, there remains significant room for improvement.

The interactive electronic pegboard developed in this study not only incorporates all the features of the Neofect Smart Pegboard but also allows patients to record their outcomes in the cloud after each practice session through software and hardware integration. The accumulation of data then enables the system to tailor rehabilitation courses to individual patient needs. The proposed interactive electronic pegboard also offers greater flexibility in gamification, as users can expand their rehabilitation options by simply purchasing additional game modules. The system's distinctiveness and progression are illustrated in Table 1.

Table 1. A Comparative analysis of Neofect Smart Pegboard vs. Interactive Electronic Pegboard

Category	Description	
Device Name	Neofect Smart Pegboard	Interactive Electronic Pegboard
Objectives	Manual Dexterity, Visual Motor integration, Visual Cognition and Shape Recognition	Provides analysis for Manual Dexterity, Hand-Eye Coordination, Visual Cognition, and Shape Recognition.
Dimensions	557(W) x 353(H) x 32(D) mm	258(W) x 163(H) x 7.5(D) mm
Weight	6.32kg	490 g
Sensor	Hole sensor (Magnetic Recognition)	Capacitive displacement sensor
Speaker	Built-in speaker for auditory feedback	Built-in speaker for auditory feedback
Digital Training Program	Delivers outcome-driven digital rehabilitation training targeting upper limb, visual/spatial, and cognitive capabilities.	Provides outcome-driven digital rehabilitation training tailored to enhance upper limb, visual/spatial, and cognitive abilities.
Visual Feedback	Featuring high-intensity LEDs, this system offers visual cues to guide the placement of pegs.	Utilizing the tablet screen, the system provides prompts to guide users in placing the building blocks in the correct positions.
Auditory Feedback	Enhances the training experience by utilizing voice and sound effects for patient	By incorporating built-in voice and musical effects on the tablet, patients receive prompts

	guidance.	indicating the correctness of their responses, thereby enhancing the training experience.
Various Peg Sets	By effortlessly substituting pegboards, individuals can access diverse rehabilitation training tailored to their specific training objectives.	Utilizing the system's diverse gaming features, one can enhance rehabilitation training versatility by easily replacing the tablet's outer casing, thereby adapting the training pegboard to individual rehabilitation needs.
Training Result	Presents real-time test results, including total time, the number of successful pegs, average peg movement time, and success rate.	Provides real-time display of test results, encompassing user goal achievement rate, the number of successful pegs, analysis of reasons for unmet goals (related to motion or cognitive issues), success rate, and goal predictions.
Session Training	Users can customize training sessions by selecting specific exercises to suit their needs and follow the tailored session accordingly.	Therapists can pre-set relevant exercises or customize training programs based on user needs, adjusting them according to the observed outcomes.
Wide Range of Difficulty Level	Can configure various difficulty levels for the game and adjust settings such as time, speed, and the number of blocks.	Can adjust game difficulty and modify settings such as time, speed, and the number of blocks. Additionally, the system supports both offline and online practice, featuring online question and answer functionalities.

The primary objective was to devise personalized treatment plans that address the specific needs and goals of each patient. This systematic approach contributes to enhancing their capabilities in everyday life and professional endeavors. The challenges inherent to traditional assessment and training approaches, such as heightened time demands and difficulties in precisely monitoring disease progression or managing data entry errors, can be effectively alleviated through the integration of digital technology[24, 25]. Thus, this study developed a prototype of an innovative interactive electronic pegboard for the rehabilitation of stroke patients. By integrating electronic sensing technology and wireless network capabilities (i.e., Wi-Fi), the proposed system enhances the precision and effectiveness of rehabilitation training and assessment. Digitalization of the process facilitates accurate tracking of a patient's progress and enables individualized assessments of movement and cognitive issues, thus promoting high-quality personalized healthcare[26, 27].

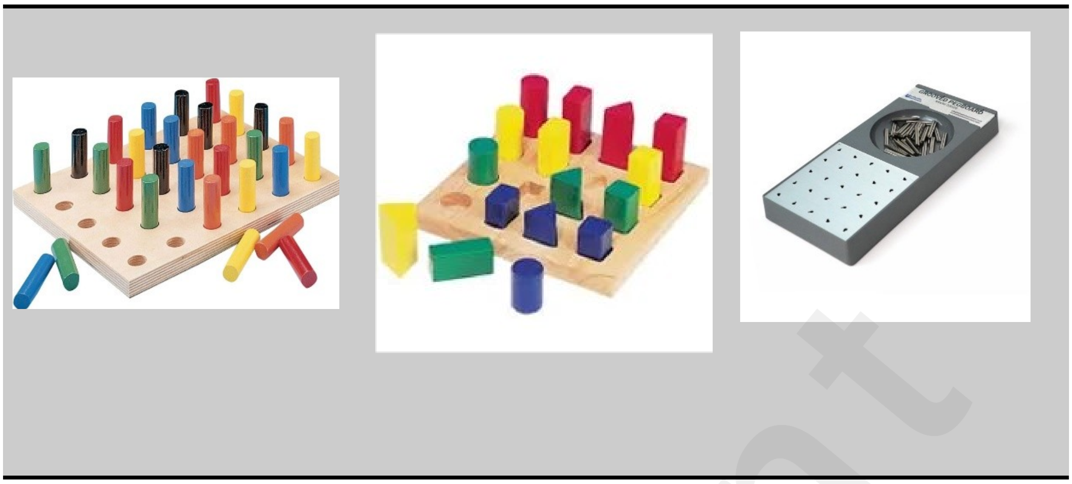
Methods

Pegboards are widely employed in rehabilitation facilities to train patients in lateral coordination, manual dexterity, hand-eye coordination, as well as visual perception and attention. However, in the rehabilitation process, stroke patients need to engage in active and prolonged exercises. The repetitive and high-intensity nature of these exercises can lead to boredom, fatigue, or laziness among patients, making it challenging for them to remain focused. Immediate feedback and interaction are both effective approaches to increasing user engagement.

Due to the individual differences in the rehabilitation needs of stroke patients, comprehensive rehabilitation records can assist physicians and therapists in designing personalized training programs. The use of traditional pegboards relies on manual documentation by healthcare professionals, which can be cumbersome and prone to errors in clinical settings. Furthermore, the majority of traditional training equipment cannot synchronize training, assessment, and testing for functions such as manual dexterity, visual perception, and attention. Without a means of integrating singular evaluations, there is a lack of objective assessment criteria (Table. 2). While the Neofect Smart Pegboard reduces the costs of human resources, it fails to achieve individualized prescription and tracking functionalities.

Table 2. Traditional tools for manual dexterity and cognitive training and assessment

Pegboard board	Shape and color	Assessment tools



The proposed system comprises an iPad, responsive building blocks, and three task casings (Fig. 1). We validated the feasibility of the proposed pegboard for clinical training and assessment through evaluation of its functionality and usability.

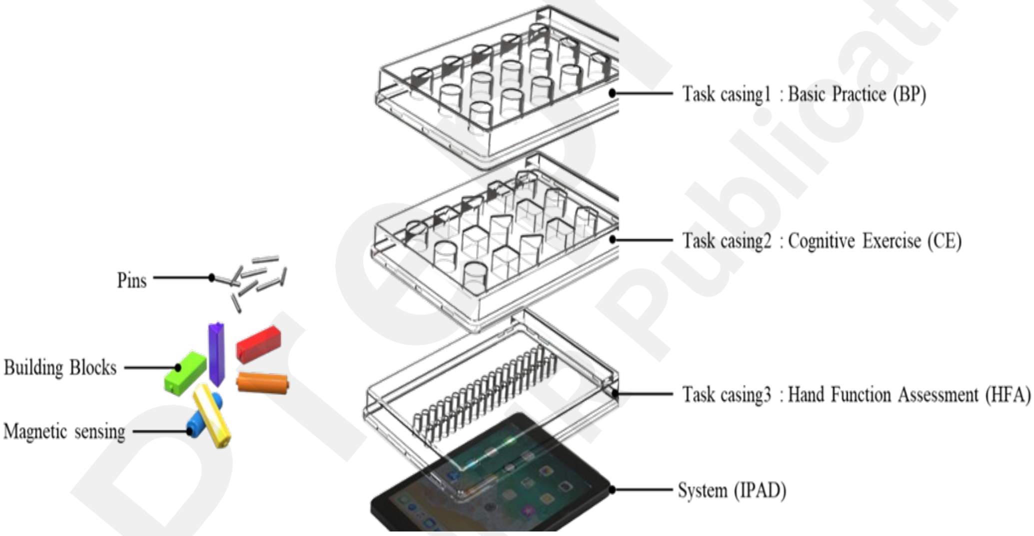


Figure. 1 System design for interactive electronic pegboard

The building blocks used in the experiment are constructed from conductive materials (magnetic sensors), Analogous to the principles of touch panels, when these conductive building blocks come into contact with the panel, they facilitate communication with the iPad through capacitive touch interactions. The principle underlying color recognition employs the multi-touch capability of the tablet. It relies on the distance between points and the single or multiple touch conditions as the basis for the computer's color interpretation. Each building block has distinctive visual patterns on its rear surface. When a user places a building block onto the tablet, the tablet's capacitive touch technology detects the applied force area, which is then used to determine the color of the block. A flowchart of the system is depicted in Fig. 2.

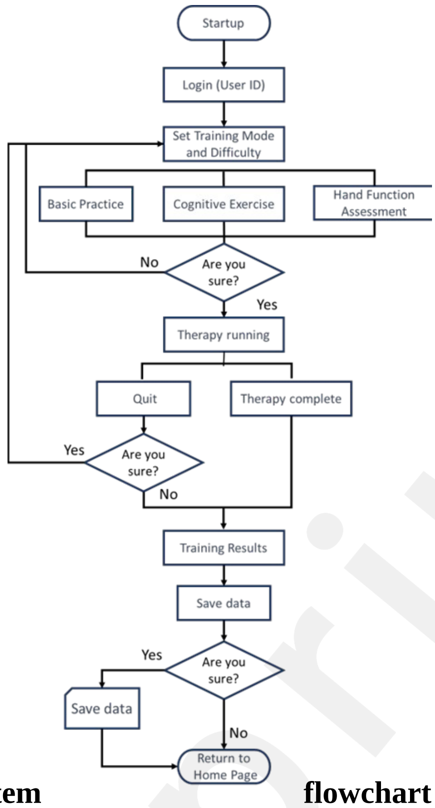


Fig. 2 System flowchart

The system comprises three modes: basic practice (motor training), cognitive exercises (shape and color matching), and electronic Purdue tests. Each mode includes a range of difficulty levels. All three modes can be configured as timed or untimed. In the timed mode, users must complete tasks within the designated time, and algorithmic exercises and test evaluations are conducted based on the achieved results. Relevant reports are accessible to both therapists and patients, and all data are automatically stored in the cloud. In the following, we describe the modes and their difficulty levels in detail:

(1) Basic practice (BP):

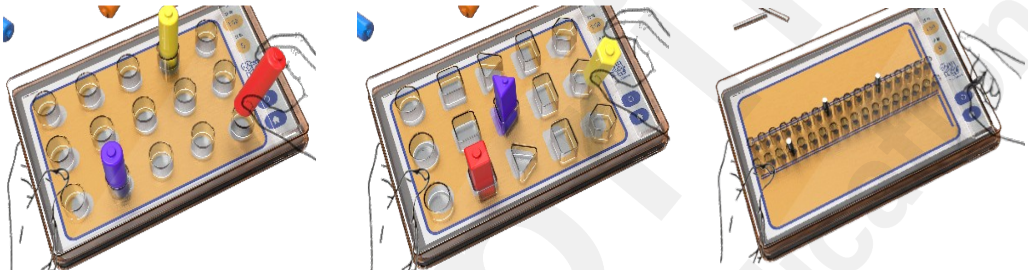
In this mode, patients are required to match signals displayed on the tablet screen with corresponding building blocks, as illustrated in Fig. 3a. At the basic level, patients are only asked to place blocks in their designated positions. The intermediate level asks for precise alignment of both color and position. The advanced level incorporates a speed variable to augment the complexity of the task.

(2) Cognitive exercises (CEs):

In this mode, patients engage in the assessment of cognitive concepts. Similar to the BP mode, they are required to match building blocks to the pattern presented on the screen to earn points. However, additional cognitive challenges are introduced, such as not only placing the blocks in the correct positions but also considering their shape and color, as shown in Fig. 3b. In advanced levels, a speed variable is introduced to heighten the complexity of the task.

(3) Electronic Purdue test (EPA):

This mode was designed in alignment with the principles of the Purdue Pegboard Test, where illuminated signals guide patients in the sequential insertion of pegs into corresponding holes. This assessment comprises distinct 30-second trials for the left hand, right hand, and both hands. The platform automatically calculates the average completion time over three trials (see Fig. 3c).



Basic practice (BP) b) Cognitive exercise (CE) (c) Electronic Purdue test (EPA)

Fig. 3 Three modes of proposed pegboard task

System login & personal record and prescription

Big data analytics enables the system to efficiently estimate personalized rehabilitation prescriptions. To accomplish this, the system incorporates a user login mechanism for the effective management of individual records. The three modes include pre-set exercises encompassing a variety of directional movements. By analyzing repeated user interaction records, machine learning estimates individual needs and prescriptions. It focuses on repetitive exercises tailored to address the weaker areas of each patient.

Data collection

In order to assess whether this design can meet users' needs for product functionality, this study adopts the Happiness, Adoption, and Task Success metrics from Google's UX framework, HEART, as indicators to examine users' subjective perceptions of the prototype. These metrics include satisfaction, acceptance (Adoption), such as interest in the prototype, and Task Success, which represents the users' success rate in accomplishing specific tasks within the product. Accordingly, these metrics serve as a means to collect emotional experiential information from users during operation.

To validate the benefits of the proposed system, we collected the following data:

1. We assessed discrepancies between the time and difficulty settings of the proposed system and the patients' capabilities.
2. We investigated the correlation between the scores calculated by the proposed system and therapist evaluations of hand function/cognitive abilities to determine the accuracy of the system.
3. We distributed a usability questionnaire to gather user feedback.

Participants

The pilot study was conducted at the Department of Physical Medicine and Rehabilitation, Chang Gung Hospital, Taiwan. The research protocol underwent rigorous scrutiny and received approval from the Research Ethics Board of Chang Gung Hospital (Reference No: IRB/REC No: 202301197A3). Ten older adults aged between 65 and 80 undergoing rehabilitation after a mild stroke were recruited for this study. All participants were right-handed. Prior to participation, each subject provided informed consent by signing the necessary documentation.

Experiments

This pilot study primarily focused on digitizing rehabilitation records using BP and CE modes as specific test components. The aim was to evaluate the differences between the time, operating mode, and difficulty settings of the proposed system and the capabilities of the patients. Furthermore, we aimed to confirm the efficacy of the system by assessing the correlation between color and shape in evaluations of hand function and cognitive abilities. Finally, a usability questionnaire was employed to collect user feedback on ease of use and enjoyment. The conceptualization of this system originates from the transformation of traditional rehabilitation methods into electronic formats, aiming to alleviate the workload of healthcare professionals, enhance the precision of rehabilitation prescriptions, digitize records, and introduce an element of entertainment into patient treatment. We have commenced extensive testing with a large number of participants to ascertain the clinical effectiveness of the system.

Operating modes and time settings

All participants were asked to use both BP and CE rehabilitation modes. The practice sessions involved completing 15 basic shape pairings within 30 minutes and 15 shape and color recognitions within 40 minutes. The completion rates for each session were examined to validate the appropriateness of the time settings on the prototype.

Correlation between manual dexterity and cognitive function

To investigate whether the proposed pegboard could enhance both manual dexterity and cognitive function, all participants underwent initial measurements of grip and pinch strength. Following this, assessments of manual dexterity were conducted using standardized tools such as the box-and-block test (BBT). Subsequently, participants underwent cognitive assessments, including the trail-making test (TMT) and the mini-mental-status examination (MMSE). This sequential process was designed to examine the correlation between the use of the proposed pegboard and the enhancement of both manual dexterity and cognitive abilities.

Usability assessment

To comprehensively assess user interactions with the proposed system, this study employed the system usability scale (SUS) [28]. Administered through a Likert five-point scale, the SUS probes user perceptions of the system's difficulty and user acceptance of the system in order to understand whether the time and task settings were appropriate. The insights gained from user experience serve as valuable references for enhancing and refining prototypes.

Data analysis

This study utilizes clinical assessments conducted by physicians to evaluate participants' physical and mental conditions, testing conditions, and experimental procedures, for the purpose of recommending their participation in prototype testing. Throughout the testing phase, there were no missing data or participant withdrawals. Questionnaires were administered sequentially, with responses entered into SPSS for statistical analysis without undergoing any transformations.

This study utilized SPSS software version 20.0 for all statistical analyses. Data analysis focused on examining differences in operating modes, time settings, and difficulty levels in comparison to patients' capabilities. Furthermore, to explore potential associations between participants' manual dexterity and cognitive faculties among stroke patients, we employed the Spearman rank correlation coefficient. Pearson correlation coefficients were used to assess the correlation between BP-1 completion rates and scores of BP-2, CE-1, and CE-2 pertaining to accuracy/completion rates. This analysis aimed to investigate the relationship between operational proficiency and cognitive abilities. A p of < 0.05 was set as the measure of statistical significance. This study also analyzed user experiences to assess the feasibility of digitized manual dexterity and cognitive function training. These analytical approaches enhance the scientific rigor of our findings and provide a nuanced understanding of the interrelationships among the variables under investigation.

Results

Demographic data

The gender and age distribution of the ten participants in the study are presented in Table 3.

Table 3. Demographic data of participants

Variable	*Number*	*Percentage*
Gender		
Male	6	60%
Female	4	40%
Age (years)		
55-65	3	30%
66-75	4	40%
76-85	2	20%
86+	1	10%

Test results of operating modes and time settings

The findings indicate that even when utilizing their dominant right hand, the vast majority of participants encountered difficulties in successfully completing tasks within the allocated time frames of the prototype (30 minutes for BP and 40 minutes for CEs). Such observations indicate that when using the proposed system to complete rehabilitation tasks, participants encountered certain limitations.

The experiment was broadly divided into two phases. In BP-1 (Basic Practice 1, motor training), the highest achievement was 12 out of 15. However, upon transitioning to BP-2 and introducing color variables, some participants experienced a significant decline in operating speed and accuracy, though the highest score of 12 was maintained. In Module 2, similar to BP-1, participants were required to complete 15 block pairings within 30 minutes in CE-1 and 15 pairings with color and shape variables within 40 minutes in CE-2. The best performance in CE-1 was 11 out of 15. However, the introduction of color variables in CE-2 meant participants were unable to complete tasks within the designated time with a corresponding rise in error rates; the highest score remained at 11 out of 15. The test results of difficulty and time settings from BP-1 to CE-2 indicate a gap between the current time settings and the capabilities of patients(Table 4).

Table 4. User performance

Case	*BP-1*	*BP-2*	*CE-1*	*CE-2*
01	53% (8)	53% (8)	73.3% (11)	46.6% (7)
02	80% (12)	73.3% (11)	73.3% (11)	60% (9)
03	80% (12)	66.6% (10)	73.3% (11)	73.3% (11)
04	66.6% (10)	66.6% (10)	73.3% (11)	60% (9)
05	73.3% (11)	66.6% (10)	73.3% (11)	53.3% (8)
06	80% (12)	80% (12)	73.3% (11)	73.3% (11)
07	60% (9)	53.3% (8)	60% (9)	53.3% (8)
08	60% (9)	60% (9)	53.3% (8)	53.3% (8)
09	53.3% (8)	46.6% (7)	46.6% (7)	46.6% (7)
10	66.6% (10)	60% (9)	66.6% (10)	60% (9)

* BP-1: excluding color recognition variations; BP-2: introducing color perception variables

* CE-1: excluding color recognition variations; CE-2: introducing color perception variables

Relationship between system score and functional assessments

The experimental results indicated a negative correlation between participants' performance in BP-1 and CE-1 and the BBT, suggesting that with longer training durations, the effectiveness of training for manual dexterity and coordination abilities in patients' hands decreased. Furthermore, after multiple sessions of color and shape cognition exercises and tests in BP-2 and CE-2, there were significant changes in participants' performance in the TMT, confirming that the cognitive training was helpful to the participants. Finally, as illustrated in Table 3, among the ten participants, there was a significant correlation between the MMSE scores and color and shape cognition scores of the BP-2 and CE-2(Table5).

Table 5 Correlations between system scores and dexterity/cognitive evaluations

Evaluations	**BBT**	**TMT**	**MMSE**
BP-1	-0.63**	0.21	0.32
BP-2	-0.58**	0.41*	0.52*
CE-1	-0.72**	0.29	0.37
CE-2	-0.41	0.53**	0.61**

Spearman’s rank correlation analysis (n=10), *: p<0.05, **: p<0.01

BP: basic practice; CE: cognitive exercise; BBT: box-and-block test; TMT: trail-making test; MMSE: mini-mental-state examination

In this study, Pearson's correlation coefficients (r) were employed to assess the potential association between patients' operational proficiency (BP-1) and cognitive abilities (BP-2, CE-1, CE-2). The correlations for each domain were as follows: BP-2 ($r=0.911$, $p<0.001$); CE-1 ($r=0.041$, $p=0.004$); CE-2 ($r=0.852$, $p<0.002$)(Table 6). In summary, a series of test results indicate that as patients engage in cognitive tasks, their operational capacity tends to decline with an increasing cognitive load. As evidenced by the experiments, based on BP1 (with no color or shape recognition variables), participants' performance slightly deteriorates during the CE1 test involving shape recognition. Furthermore, upon progressing to BP2 (introducing color variables), participants' response efficiency diminishes compared to BP1. Subsequently, in CE2 (incorporating color and shape recognition variables), a significant disparity in overall performance becomes evident, thus confirming a notable correlation between operational capacity and cognitive load.

Table 6 The Pearson Correlation Coefficients Analysis of Manual Dexterity and Cognitive Abilities.

		Scale of Correlation Coefficient			
Domain		**BP1**	**BP2**	**CE1**	**CE2**
BP1	**Pearson Correlation**	1	.911**	.653*	.852**
	Sig. (2-tailed)		.000	.041	.002
	N	10	10	10	10

* Correlation is significant at 0.05

** Correlation is significant at 0.01

System usability

In order to develop the prototype of the pegboard for functional and task assessments, questionnaire interviews were conducted simultaneously to collect user feedback for this study. In the usability assessment, approximately 70% of the participants reported that the proposed system was notably user-friendly (Fig. 4a). A significant consensus was also observed among participants regarding the transition from traditional building blocks to electronic blocks during BP training, with nearly 70% finding that the proposed system was engaging. Note that when users entered the next stage of CE training, only 50% of the participants considered the platform to be interesting (Fig. 4b). Finally, in the evaluation of task difficulty, the majority of participants (nearly

90%) perceived the BP training tasks as easy and simple. However, upon advancing to the more complex CE training, which involved increased shape and color recognition, a noticeable increase in perceived task complexity was observed. Only 20% of the participants regarded this phase as easy, while the vast majority found it somewhat difficult and challenging (Fig. 4c).

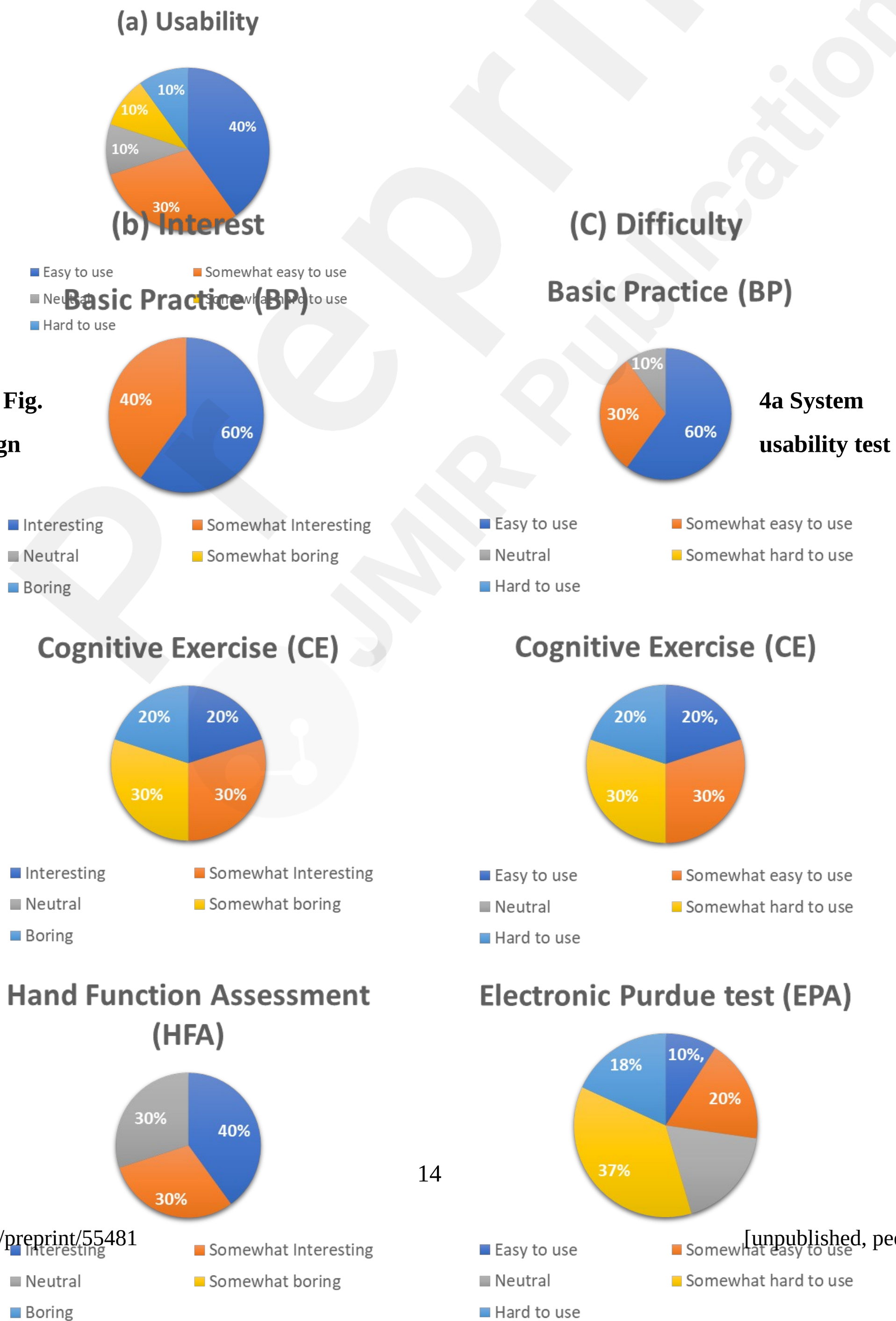


Fig. 4a System usability test design

Fig. 4b User acceptance testing **Fig. 4c Operational difficulty testing**

Discussion

Prototype setup and testing

In the preliminary investigation, we found that the preset time frames on the prototype did not align with the capabilities of users. In this experiment, none of the participants were able to complete the tasks within the designated time, which could be attributed to declines in hand/finger muscle strength, manipulation, walking ability, and information processing speed associated with aging, as documented in previous relevant studies. These findings emphasize the importance of considering age-related factors in the design and calibration of such interactive systems[19, 20, 28]. Additionally, due perhaps to the lack of electronic records, therapists tended to focus more on how many blocks users could complete rather than paying attention to how far users were from the goal. Therefore, digitized rehabilitation could help to clarify a patient's recovery status. Moreover, in both the BP-1 and CE-1 modes, the electronic block exercises exhibited a negative correlation with improvement in motor skills. This could be attributed to factors such as time settings or user habits. At the same time, aging could contribute to declines in dexterity and attention[29, 30]. Walters et al. applied eye-tracking metrics during commonly-used dexterity tests and found that older individuals exhibited poorer visual focus and reaction capabilities[31]. Therefore, in future studies, we plan to explore the relationship between eye movements and performance for each of the system tasks for both healthy participants and stroke patients [32-35].

Relationship between system scores and functional assessments

While the results from BP-1 and CE-1 indicate a significant negative correlation between digital block exercises and manual dexterity, surprising outcomes emerged in the subsequent BP-2 and CE-2 training sessions, when variations in color and shape were introduced. The majority of participants exhibited a notable correlation between performance levels on the TMT and MMSE. This implies a correlation between the patients' operational capabilities and cognition. In the past, discerning whether difficulties faced by patients in completing motor tasks stem from operational capabilities or cognitive issues with traditional rehabilitation aids has been challenging. Therefore, our system not only records patient completion rates but also conducts an analysis of color accuracy. By doing so, the system not only assesses the patients' operational abilities but also provides an initial clarification of the patients' cognitive status. These unexpected findings suggest that the increased cognitive challenges posed by engaging in exercises with diverse shapes and colors could stimulate and potentially influence participants' manual dexterity and attention-switching abilities, consequently enhancing users' cognitive functions. Moreover, this digitized tool, enhanced with guiding indicator lights, not only facilitated precise block pairings but also emerged as a critical element in enhancing users' visual perception and attention[36-38]. Simultaneously, the incorporation of sound and musical guidance can further enhance the training's engaging nature.

Evaluation of usability, appeal, and difficulty

The majority of participants perceived the proposed interactive electronic pegboard as highly user-friendly and easy to operate. This can be attributed to the size of the prototype, which closely resembles that of traditional training pegboards, minimizing the degree of adaptation needed. Moreover, the design of the pegs adheres to common training block proportions, which are crafted in a one-to-one ratio to ensure they are easy to grasp – not too large and not too small. In addition, a significant advancement in this design lies in the elimination of manual recording by therapists along with the need for separate stopwatches. This represents notable progress, as traditional rehabilitation sessions of this nature often require one-on-one interaction with healthcare professionals. This is not only labor-intensive, but also error-prone.

In this preliminary trial, more than two-thirds (70%) of the participants considered BP training to be very simple, and almost 60% of the participants found this digital tool to be interesting. However, as operating constraints increased (considering both shape and color elements simultaneously), most participants reported that the tasks became more challenging. Flexibility is a major advantage of this tool as it is easy to adjust both the difficulty level and the richness of training. This feature is particularly crucial for patients requiring long-term rehabilitation. Taking stroke patients as an example, prolonged rehabilitation not only imposes physical strain but also the repetitive nature of exercises without feedback can lead to a lack of motivation and fatigue among patients. Gamification of rehabilitation can assist in alleviating the monotony associated with extended rehabilitation sessions by incorporating game-like variations. Simultaneously, for stroke patients requiring long-term rehabilitation, maintaining rehabilitation efforts at home post-discharge is a critical determinant of recovery effectiveness. In contrast to conventional rehabilitation approaches, this electronic rehabilitation assistive equipment demonstrates notable progress in terms of labor costs, rehabilitation documentation, medical precision, and the gamification of rehabilitation, making it a promising trend in future healthcare. In the future, we plan to connect the device to multi-user platforms, so that a competitive dimension can be introduced to stimulate engagement [39-41]. In this initial experimental trial, none of the participants were able to complete the tasks within the designated time, suggesting that there is room for improvement in terms of the time settings of the prototype. Simultaneously, concerning clinical needs, rehabilitation records serve as crucial reference indicators for the formulation of rehabilitation programs (prescriptions). To further enhance this system as a rehabilitation aid, the system has initiated the design of graphical interfaces to visualize the rehabilitation process and progress. This facilitates healthcare professionals in promptly understanding the improvement status of patients' hand functionality. In the next phase of study, we plan to focus on refining and enhancing these aspects[42, 43].

Conclusion

In this investigation, we developed a novel interactive electronic pegboard – a comprehensive software and hardware system specifically crafted for stroke rehabilitation. This system was used to evaluate dexterity and cognitive functions through three task types and multiple demonstration patterns.

We recruited stroke patients who had previously utilized conventional rehabilitation methods and asked them to perform preliminary tests on the proposed system. Through meticulous data analysis, we assessed the hand dexterity and cognitive functional abilities of the patients. The initial test results indicate that the proposed system is effective in terms of both rehabilitation and assessment. In the future, following further enhancement and stabilization of the system, we plan to conduct extensive usability testing with a large user (patient) population. The testing protocol will encompass user interactions, message comprehension, and interface operability, among other aspects. Additionally, we will employ the System Usability Scale (SUS) questionnaire to validate the clinical feasibility of the product. Furthermore, to ensure the reliability and validity of future product applications in clinical settings, the experiment will cautiously assess the linear correlation of variance during large-scale trials, and employ power analysis to analyze Significance Level, Power, and Effect Size. This is to ensure the rationality of the clinical statistical sample size and enhance the reliability of the statistical analysis. The primary objective of this research was to not only bridge the gap between clinical needs and product development but also to go beyond commercially-available products by enabling tracking of individual rehabilitation progress[44-47]. This tracking enables the development of personalized rehabilitation programs based on individual differences [48-51]. Ultimately, our goal was to develop an intelligent system capable of delivering user-friendly optimized rehabilitation regimens to meet the diverse needs of users, and substantively contribute to the benefits brought about by clinical validation.

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Supplementary Files