Comparative Study of Tangible Tabletop and Computer-Based Training Interfaces for Cognitive Rehabilitation

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Abstract. Computer-based training (CBT) has lately been applied for the cognitive rehabilitation of stroke patients. However, most CBT programs do not consider body movement, which is important for cognitive rehabilitation because body movement (action) and thought (mind) are deeply correlated. Based on the coupling of action and mind, we propose a tangible tabletop-based training (TTBT) platform, E-CORE. We conducted a comparative study between E-CORE (TTBT) and RehaCom (CBT), for which we recruited eight patients as participants. We used the performance score yielded by the Intrinsic Motivation Inventory (IMI), the System Usability Scale (SUS), and the Questionnaire for User Interaction Satisfaction (QUIS) for quantitative analysis, and observation and semi-structured interviews as tools for qualitative analysis. Even though the user group was comparatively small, we found that E-CORE (TTBT) increases patients' motivation for rehabilitation.

Keywords: Cognitive rehabilitation · Stroke · User interfaces · Tangible tabletop · Computer-based training

1 Introduction

Approximately 800,000 people suffer strokes each year [1]. Stroke survivors can experience various impairments of their motor, sensory, and cognitive skills [2]. These defects result in disabilities related to concentration, memory, simple mathematical computations, and spatial visualization and orientation [3, 4]. In such cases, cognitive training can help improve stroke patients' cognitive functions and help slow deteriorating cognitive impairments [5, 6]. Studies on animal as well as humans have shown that intensive and repetitive training helps reduce impairment in stroke patients [7]. Motivation is an important factor in the effects of cognitive rehabilitation training. Motivated patients tend to participate more actively in rehabilitation programs because

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they consider rehabilitation to be a means of recovery [8]. Rehabilitation programs can integrate gaming features into rehabilitation training to enhance patients' motivation. Furthermore, gaming features-based rehabilitation has been reported to enhance motivation in adults patients undergoing physical, cognitive, and occupational therapy following a stroke [9]. However, the role of body movement in cognitive rehabilitation of previous training program has not been studied as extensively. Body movements should be considered when designing a cognitive training program because human actions (body) and thoughts (mind) are intimately connected [10]. With regard to the coupling of human action and thought in cognitive rehabilitation, we propose tangible tabletop-based training (TTBT), which relies on physical manipulation and cognitive tasks, as superior to conventional computer-based training (CBT), which involves the use a keyboard and mouse for cognitive rehabilitation. We conduct a comparative study to establish the superiority of TTBT over CBT programs.

In this paper, we make the following assumptions: First, there is a statistical preference for TTBT in terms of test scores for motivation and usability. Second, there is a correlation between MMSE (Mini-mental State Examination) and the motivation score on IMI (Intrinsic Motivation Inventory).

2 Background and Related Work

In this section, we review existing work related to the comparison of input interfaces in cognitive rehabilitation.

2.1 Traditional Physical Object-Based Training

Traditional cognitive training using physical tools, such as shapes and images, is a typical method in therapy. Training using physical tools is familiar to patients, and has the advantage of immediate feedback. However, there are limitations due to the cost of setting up the tool and the variety of training content [11]. In addition, in traditional rehabilitation it is difficult to evaluate the patient's performance objectively.

2.2 Computer-Based Training (CBT)

Computer-based training (CBT) can provide real-time performance feedback and personalized programs [12]. Although CBT was developed to solve problems with traditional cognitive training interfaces, limitations in it persist. Patients are not familiar with computer interfaces and find it difficult to use a mouse and keyboard-based panel interface [13, 14]. An instance of a CBT program is RehaCom, shown in Fig. 1.

RehaCom: RehaCom is a cognitive training program developed to enhance concentration, memory, and visualization. The system comprises a keyboard and a mouse panel [15]. It allows easy and more extensive access to its record as numerous hospitals use it.

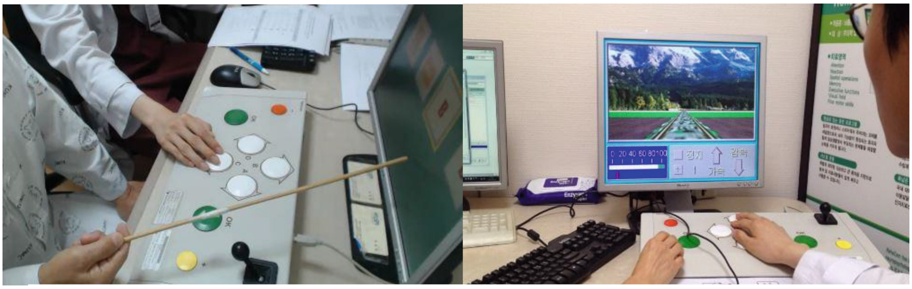


Fig. 1. RehaCom as an instance of computer-based training for cognitive rehabilitation

2.3 Tangible Tabletop-Based Training (TTBT)

The bulk of research on cognitive rehabilitation has focused on specific cognitive domain effects such as attention and memory [11, 12]. A TUI (tangible user interface) allows users to interact with a digital device through the manipulation of commonplace objects using a computer system [16, 17]. The physical interaction with real objects can improve the quality of training for patients who need cognitive and/or motor rehabilitation [18].

E-CORE (Embodied Cognitive Rehabilitation System): Based on the concept of embodied cognition, E-CORE is a novel cognitive rehabilitation system that can delay or prevent cognitive problems using tangible objects and a tabletop interface to train patients to perform activities of daily living (ADL) [19]. Examples of tangible objects are shown Fig. 2. Compared with computer-based training (CBT) that involves singular mental tasks using keyboard and mouse, E-CORE can reinforce the coupling of body movement and cognition. Embodied cognitive rehabilitation helps improve patients' cognitive functions while they enjoy the relevant exercises. In this study, we report on the development of a cookie-making game as part of the instrumental ADL. The task involves creating the shape of cookies using a cookie cutter, calculating the proper temperature of the oven to bake them, moving the cookies, serving syrup using a brush, and sprinkling toppings on the cookies from containers.

Fig. 2. E-CORE system as a tangible tabletop-based training for cognitive rehabilitation

3 Experiment

3.1 Participants

The eight participants of our study were stroke inpatients (four females and four males) from a hospital. They were recruited according to criteria for the Mini-mental State Examination (MMSE). Patients who scored between 12 and 26 on the MMSE were considered suitable for the experiment. In addition, the participants could move their upper limbs, as the two interfaces being compared required the ability in subjects to move their upper limbs in order to grasp objects and push buttons. We received informed consent for all procedures was obtained from each participant and caregiver, and the study was approved by institutional review board of Korea University Anam Hospital. The range of the participants' MMSE scores varied from 13 to 26 (M = 19.75 ± 4.83). The range of their ages was 48 to 78 years (M = 64.25 ±13.26). This information is shown in Table 1.

Table 1. General Characters of Participants

Subject#	Charateristics					
	Gender	Age (y)	Affected side	Diagnosis	MMSE	Academic level
1	F	74	Right	Rt. PCA territory infraction	16	Less than a high school
2	M	74	Left	Lt. MCA, ACA territory infarction	14	High school graduates
3	M	49	Right	Rt. BG ICH	23	Less than a high school
4	F	78	Right	Rt. F-T-P SDH	13	Less than a high school
5	M	49	Left	SAH with IVH	23	High school graduates
6	F	67	Right	Rt. cerebellar ICH with IVH	26	Less than a high school
7	M	75	Right	Rt. Lat. Medullary infarction	23	Less than a high school
8	F	48	Right	Lt. MCA territory infarction	20	High school graduates

3.2 Settings

To compare the levels of motivation and usability of body movement in E-CORE (TTBT) and CBT, we chose RehaCom as the CBT program. The methods used for task assessment are shown in Fig. 3. We set-up our study in an enclosed space as this allowed for a controlled environment for the study that could be replicated. Moreover, RehaCom (CBT) and E-CORE (TTBT) were placed apart in the environment. Therefore, the evaluation of experiments on each proceeded independently of the other.

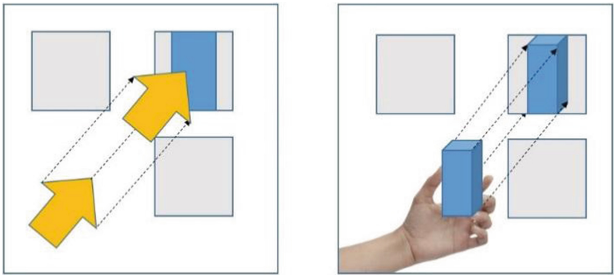


Fig. 3. Inputs in the cognitive training task: 2D inputs, such as a mouse or a keyboard in the CBT program (left) and 3D inputs, such as tangible objects in the TTBT program (right)

3.3 Measures

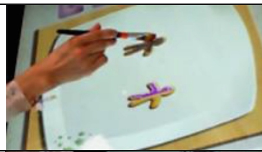
The MMSE score was used to screen patients and find a correlation in motivation or usability test scores. In this study, we used several types of quantitative and qualitative methods. The factors that were studied are shown in Table 2.

We recorded participants' statistics, such as reaction time, error rate, and verbal reactions, to identify user engagement and preferences [20]. As post-questionnaires, we used the Intrinsic Motivation Inventory (IMI), the System Usability Scale (SUS), and the Questionnaire for User Interaction Satisfaction (QUIS) to evaluate the participants' motivation and usability of body movement, and the usability of the two cognitive rehabilitation interfaces [21, 22]. All scores were compared using the Wilcoxon signed-rank test because of the small number of participants.

4 Results

Data for our study were collected in a number of ways. A quantitative analysis of the results are based on a statistical analysis of patients' responses to the questionnaires (IMI, SUS, QUIS) and performance results. A qualitative analysis of observations was conducted by using our video and audio records, and semi-structured interviews were used to contextualize the quantitative findings.

Table 2. The factors of RehaCom (CBT) and E-CORE (TTBT)

Factors	CBT (RehaCom)	TTBT (E-CORE)	
Attention	Attention and concentration training session	Following the instruction at each step	
Memory	Memorize the position of cards	Memorize cookie shape and color of syrup and toppings	
Calculation	Calculation training session	Calculate the baking temperature	
Factors	**CBT (RehaCom)**	**TTBT (E-CORE)**	
Execution	Pointing or pressing the button and using joystick	Using the cookie cutter, serving the syrup, and sprinkling toppings	
Spatial operations	Spatial operation and 2D operation training session	Recognizing the rotation of shape	

4.1 Motivation

The level of motivation was calculated by IMI, QUIS, error rate, observation, and verbal reaction.

Motivation Inventory (IMI): The IMI score of the TTBT was significantly higher than that of CBT, especially for "Interest" (TTBT: M = 3.5, SD = 1.3; CBT: M = 1.88, SD = .98), (z = 2.414, $P < .05$) and "Perceived choice" (TTBT: M = 3.38, SD = .43; CBT: M = 1.88, SD = .32), (z = 2.15, $P < .05$), whereas the "Pressure/Tension" score of TTBT was lower than that of CBT (TTBT: M = 1.62, SD = .22; CBT: M = 3.75, SD = .13), (z = 2.59, $P < .05$).

User Interaction Satisfaction (QUIS): The QUIS scores of the TTBT focusing on "User learnability" were higher than the CBT scores (TTBT: M = 4.75, SD = 0.38;

CBT: *M* = 3.5, *SD* = 0.84), (z = 2.04, $p < .05$). However, there was no significant difference between the systems in terms of the other factors.

Error Score: The error sore was transformed five-point Likert scale from 0 to 100 game score (0 ~ 20 - > 4; 21 ~ 40 - > 3; 41 ~ 60- > 2; 61 ~ 80- > 1; 81 ~ 100- > 0). The errors in the execution and spatial operations of the CBT (execution: M = 3.13, SD = .99; spatial operations: M = 2.75, SD = 1.17) were significantly higher than those for the TTBT score (execution: M = 1.25, SD = 1.04; spatial operations: M = .88, SD = .83), (execution: z = 2.42, $p < .05$; spatial operations: z = 2.13, $p < .05$). The results are shown in Fig. 4.

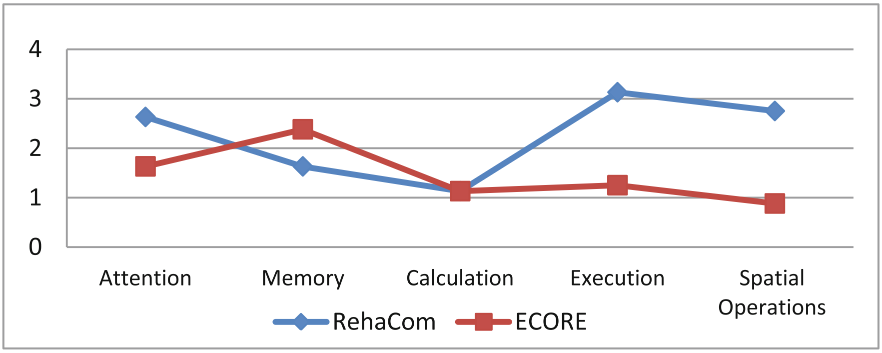


Fig. 4. Error score of both interfaces

Observation and Verbal Reactions: The methods focused on user preferences and motivation. In order to identify the preference among patients between the CBT and TTBT interfaces, we conducted semi-structured interview after the sessions. Most participants commented that both cognitive training interfaces were effective. They said that since they did not know exactly how each system worked, they preferred E-CORE's tools, which were more familiar to them. A few participants mentioned that they disliked using both digital interfaces due to their unfamiliarity with computers.

4.2 Usability and Body Movement

The usability and body movement of the interfaces were calculated through SUS, reaction time, observation, and verbal reaction

(a) **System Usability Scale (SUS):** The SUS score was calculated on a scoring form, and ranged from 0 to 100. The SUS score of TTBT (*M* = 48.75, *SD* = 22.6) was little higher than that of CBT (*M* = 46.25, *SD* = 11.10), whereas no significant differences were found in the SUS evaluation (z = .281, p = .779).

Reaction Time (RT): Except for the calculation stage, the reaction times of all stages of the CBT were higher than those of TTBT. In particular, we found that the reaction time of "Execution" and "Spatial operation" of the CBT (execution:$M = 3469.258$, $SD = 249.10$; Spatial operation: $M = 4041.5$, $SD = 208.3$) were significantly higher than those of TTBT (Execution: $M = 1353.38$, $SD = 97.10$; Spatial operations: $M = 1614.25$, $SD = 139.2$), (Execution: $z = 2.52$, $P < .05$; Spatial operations: $z = 2.51$, $P < .05$). The results are shown in Fig. 5.

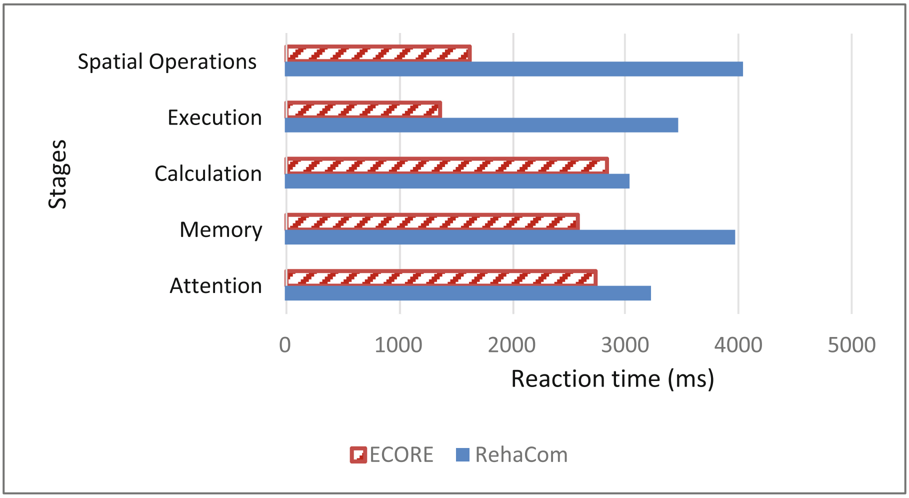


Fig. 5. Reaction time of both interfaces

Observation and Verbal Reactions: Observations were focused on physical manipulation, which were hypothesized to be important in cognitive rehabilitation using a coupling of the body and the mind [13]. We assumed that most participants would start concerning the input tool such as panel keyboard and cookie cutter. However, we observed that participants were interested in the tabletop display due to its conspicuous color and shape. While working with RehaCom (CBT), participants had difficulty using the panel keyboard even though we had explained how to use it. They preferred pointing to the display rather than using the panel keyboard. However, participants were easily able to use the tools to cut and bake cookies in E-CORE (TTBT). They reported finding that cookie-making tools, such as the cookie cutter, the brush, and the topping container, were familiar to them from daily life. Observational analysis revealed that participants were much more active and intuitive in terms of body movement (action) in cognitive training on E-CORE than on RehaCom.

4.3 Correlation Between MMSE and IMI, QUIS Score

MMSE and IMI scores were normalized to analyze the correlation. The MMSE score had a strong positive correlation with the IMI score of TTBT (Interest: $r = .82$, $p < .01$; Perceived competence: $r = .717$, $p < .05$; Perceived choice: $r = .856$, $p < .01$; pressure: $r = -.815$, $p < .05$). Further, we found a positive correlation of MMSE scores with

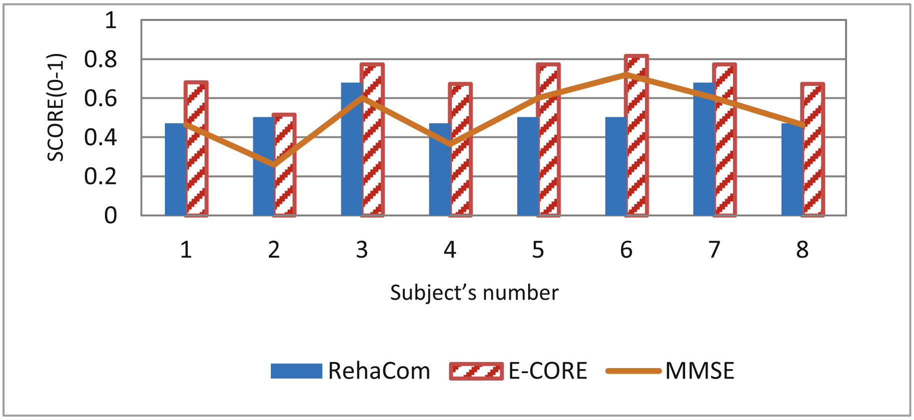


Fig. 6. MMSE with IMI scores of both interfaces

both interfaces for "User learnability" in QUIS (CBT: r = .73, p < .05; TTBT: r = .68, p < .05). The results are shown in Fig. 6.

5 Discussion

5.1 Motivation and Usability of Body Movement

We found that the participants perceived the feedback from TTBT interesting. The TTBT interface using a tabletop system appeared to be more powerful in terms of visual, aural, and tactile feedback than the CBT interface. In previous study, the tabletop system has been shown to be compatible with a multimodal feedback interface [23]. Further, we found that since the tangible objects used in TTBT were familiar to participants from everyday life, they found it easier to use TTBT than CBT [24].

5.2 MMSE Score and Motivation

The MMSE score is related to factors affecting patients' motivation in the TTBT interface. If participants had high MMSE scores, they had determined that the level of motivation provided by the TTBT interface was high. Based on observation of their verbal reactions, we concluded that the participants' positive motivational reaction to TTBT reflects the fact that the E-CORE (TTBT) task engages body movement to a greater extent, consistently with its use in ADL, than RehaCom (CBT). Therefore, since patients with high MMSE scores considered E-CORE (TTBT) an effective rehabilitation training tool, they were motivated to train with it. They found the tools provided by the former easier to handle and more interesting [8]. Furthermore, this indicates that MMSE scores and physical impairment are related. For example, grasping or rotating an object might be difficult for a patient with a low MMSE score following disability of physical movement [25]. In addition, the "learnability" score of

QUIS for both interfaces was positively correlated with MMSE scores. Patients with high MMSE scores recognized the importance of training in treating cognitive problems. That is, they were highly motivated to get better, which is important for rehabilitation.

6 Conclusion

In this study, even though the sample size used in our experiments was small, we found that E-CORE (TTBT) increases patients' motivation for rehabilitation. Because E-CORE involves intuitive body movement to manipulate tangible objects, the participants of our experiments were motivated to perform cognitive training tasks using our system. We also found that several patients with high MMSE scores perceived the E-CORE (TTBT) system to be motivating because of the novel forms of therapy that it uses; therefore, they preferred TTBT as a cognitive training program. In the future, we intend to adjust the game level and substantially redesign the components of the E-CORE system on the basis of the results of this study. Finally, we plan to conduct a longitudinal study by using E-CORE as a cognitive training system in the clinical field.

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