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Development and Usability Test of the Prototype of the "Smart Stacking Cone" Based on Dual-task Using ICT

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Abstract

Objective : This study aimed to develop prototypes of "smart stacking cones" by combining ICT to evaluate and train the upper extremity function and dual task performance in patients with central nervous system impairment, and to identify the complementary point to the completion of the device through a usability test.

Methods : This prototype comprised of a hardware and software system that enabled the evaluation and training of patients and the management of data obtained from patients' performance. Specific measurement variables were established so that patient performance could be measured correctly. Based on the measurement variables, a the prototype included a 'single task evaluation modes', 'dual task evaluation mode', 'single task training mode', and 'dual task training modes'. Additionally, a usability test was conducted to assess clinical applicability and overall satisfaction for the prototype.

Results : The results of the usability test were generally found to be appropriate. The 'content adequacy' in the usability test was the area with the highest level of adequacy and the lowest level of inadequacy. Additionally, overall 'satisfaction' in the usability test was the area with the highest appropriate and inappropriate levels. Hence, the overall satisfaction results were unstable.

Conclusion : Future studies should be conducted to identify the clinical effectiveness of the device by applying an upgraded smart stacking cone to an actual patient group.

Keywords : Dual task, ICT, Stacking cone, Usability, Upper extremity

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Ⅰ. Introduction

Research related to Information and Communications Technologies (ICTs) has been actively conducted in the health care area. ICT is primarily applied to high value-added service industries with limited supply (Kim, 2018), such as health and medical services. Occupational therapy, among the health and medical fields, helps patients return to their lives (Choi, Lee, & Jeon, 2017). In that, the latest technologies such as computer-based evaluation system, robot-based upper limb rehabilitation, and computerized cognitive programs are used for evaluation and treatment to develop the quality of therapeutic approaches (Kim & Yang, 2014; Levanon, 2013). However, applying ICT to occupational therapy tools for evaluation and treatment is still limited. Therefore, it is necessary to develop a prototype by applying ICTs to therapeutic tools.

Therapeutic activity tools typically used in occupational therapy include 'stacking cone', 'Rang of Motion (ROM) arch', and 'peg board' (Conedera & Mitchell, 2007). Among them, the 'stacking cone' is commonly used in occupational therapists to train the grasping and releasing patterns and entire upper-extremity function by stacking the cone. However, 'stacking cone' has the following limitation: patients are bored and possibly difficult to motivate because the training repeats monotonous through simple movements (Chiu, Yen, & Lin, 2018). Therapists always consider choosing an appropriate therapeutic activity so that the client can return to their meaningful occupation while thinking on how to motivate the client (Huang, Yang, Lee, & Chen, 2016).

Most of the central nervous system impairments patients who are referred for occupational therapy have motor, cognitive, and sensory disorders. Despite the complex therapeutic needs, treatment is usually provided on a single-task conditions (Kim, Son, Oh, & Park, 2011). Since a single task is performed to achieve partial functional recovery such as upper limb function or cognitive function, single task based rehabilitation has the following limitation: it is difficult to enable the independent daily activity performance of patients with central nervous system impairment (Liepert, Beauder, Miltner, Taub, & Weiller, 2000). As the limitation that a single task-based rehabilitation applied in the actual clinical setting does not reflect the complexity of daily activities has been reported, it is necessary to introduce dual task-based rehabilitation methods in the occupational therapy area.

Dual task means that participants have to perform two concurrent tasks such as upper-extremity training and cognitive training at the same time (Korbach, Brunken, & Park, 2016). It provides a dual-task interference causing a high functional load required by two or more tasks (Woollacott & Shumway-Cook, 2002). Several studies that have conducted dual task training on patients with central nervous system impairments reported various effects of dual-task performance, physical function, cognitive function and ability to perform daily activities (Lee & Jung, 2016). However, The therapeutic tools based on dual task condition using ICT are insufficient on the field of occupational therapy.

The most important process in developing therapeutic tools is considered usability test (Park, Han, Kim, Cho, & Park, 2013). Usability is a major component of the user's experience (Park et al., 2013), providing a basis for enhancing the competitive edge of the developed product (Kwahk & Han, 2002). Despite the increased utilization of applications in various fields due to the mass spread of ICT devices, most applications are still being developed without usability tests (Park et al., 2012). In particular, devices developed for rehabilitation purposes should be based on user-centered design as they are used to restore and maintain the patient's functions (Cho, Kwon, & Hong, 2014).

Therefore, this study aims to develop prototypes of 'smart stacking cones' using ICT to evaluate and train upper extremity function and dual task performance for patients with central nervous system impairment. Also, this study aimes to identify the complementary point to the completion of the device through the usability test.

Ⅱ. Methods

1. Procedures

This study was supported by the Rehabilitation R&D Service Project of National Rehabilitation Center affiliated with the Ministry of Health and Welfare (NRC RSP-2019012) for 8 months from March to November 2019, and researchers developed a prototype of the smart stacking cone using ICT. Study was approved by the Yonsei University Mirae Campus Institutional Review Board (1041849-201906-BM-093-02) to conduct usability test of the prototype.

2. Development of the prototypes of smart stacking cones

A prototype of 'smart stacking cone' was developed using ICT to evaluate and train the upper extremity and dual-task performance for patients with central nervous system impairment. This prototype is comprised of the hardware circuit and software system that enables the evaluation and training of patients and the management of the data obtained from patient's performance. Additionally, specific measurement variables were established so that patients performance could be measured correctly. Based on the measurement variables, a prototype is comprised of the 'single task evaluation mode', 'dual task evaluation mode', 'single task training mode' and 'dual task training mode'.

Information related to ICT and dual task was collected to derive content to organize the contents of smart stacking cone, and based on this, draft of the single task and dual task evaluation contents of the prototype was constructed. Additionally, the drafts of single task and dual task training contents were completed on the basis of the results of a meta-analysis study (Won, Lim, Park, & Park, 2020), which analyzed the effectiveness of dual task training on upper and cognitive functions. To identify the insufficiency of the draft evaluation and training contents, a focus group interview comprising one clinical expert with more than 5 years of experience and five professors of occupational therapy was conducted. The appropriateness of the measured variables, the specification of the evaluation mode and training mode contents, and the appropriateness of the grading system were reviewed through the first focus

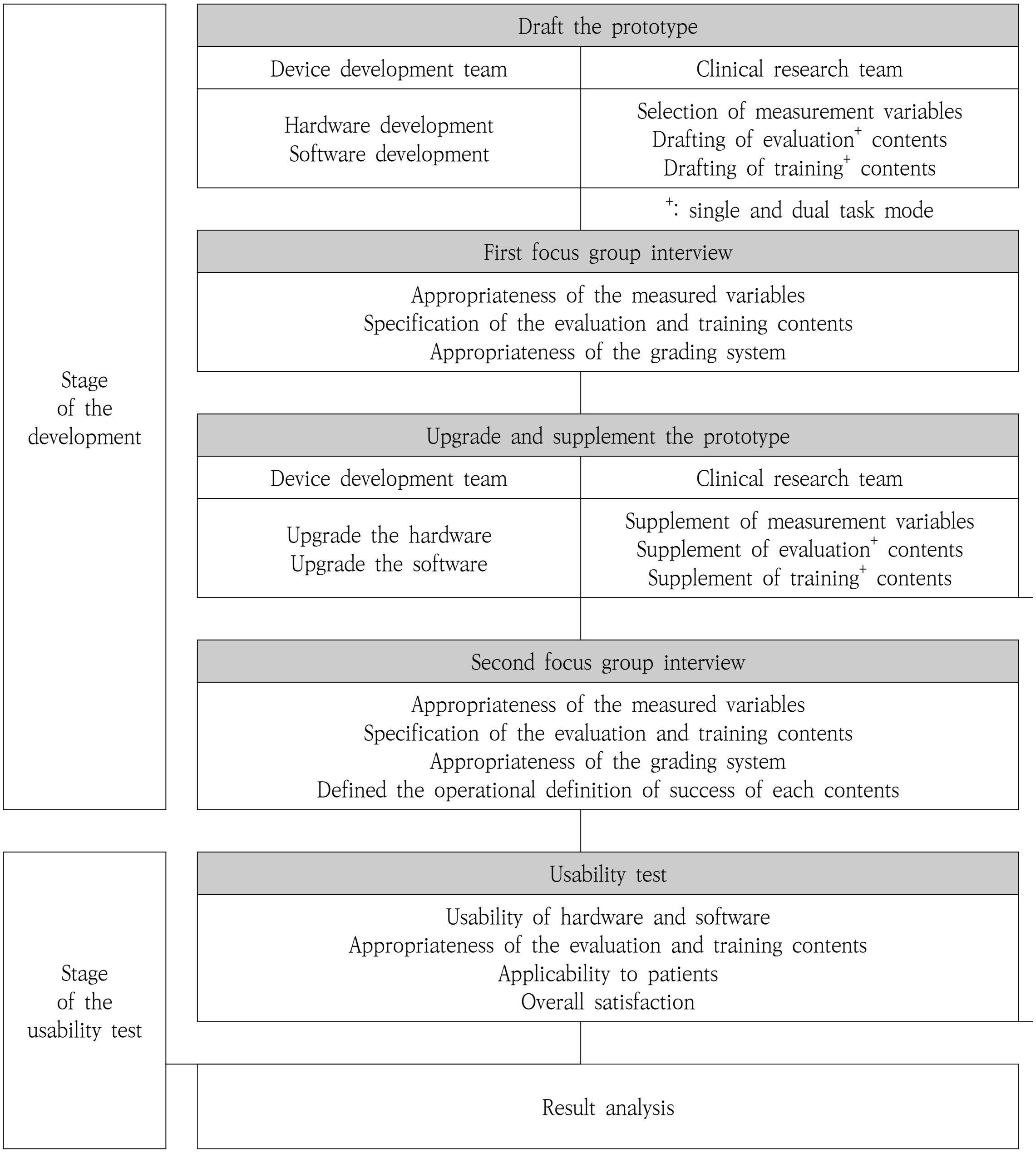


Figure 1. Flow Diagram of the Study

group interview. After supplementing and upgrading the draft of prototype, the second focus group interview was conducted again to finalize the prototype development and to defined the operational definition of success of each contents (Figure 1).

3. Participants of the usability test

A usability test was conducted to assess the clinical applicability and overall satisfaction of the prototype. The criteria for selecting participants were as follows: (1) participants who have occupational therapy licenses, (2) participants who are occupational therapists with clinical experiences of more than 3 years or a doctoral degree or higher, and (3) participants who understand and agree voluntarily with the purpose of the study. Based on the selection criteria, four participants were selected through convenience sampling. The researchers provided the participants sufficient explanation of the prototype and subsequently conducted the usability test.

4. Structured questionnaire of the usability test

The usability test was conducted using a questionnaire comprising 20 questions in four areas (8 questions about usability of hardware and software; 6 questions about usability of evaluation and training modules; 3 questions about applicability of prototype to patients; and 3 questions about overall satisfaction). The answers to the questions were based on a 5-point Likert scale, with the higher score indicating a positive response.

5. Result analysis of the usability test

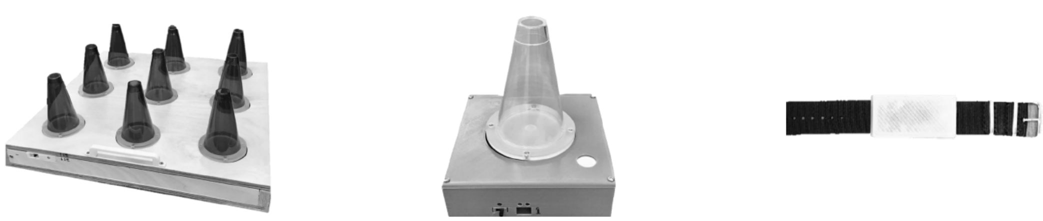
The general characteristics of participants and the results of the questionnaires were analyzed using descriptive statistics such as frequency analysis.

Ⅲ. Results

1. Development of the prototypes of smart stacking cones

1) Hardware design

The hardware is designed with the stacking board, cone plate, and wearable band (Figure 2). The 'stacking board' is a wooden board for stacking cones, with its own PCB design for the internal electrical wiring and to enhance durability. Additionally, Light Emitting Diode (LED) and Force Sensitive Resistor (FSR) sensors were applied to each lower support of the stacking board to provide visual cues and to detect the stacking cone accurately. The 'con plate' is the starting point of the performance, which was developed to measure the performance time by identifying the time from the patient lifted the cone from the plate to the time the cone was inserted into the stacking board. Finally, the 'wearable band' was developed to detect tremor by wearing it on the patient's wrist, and could be measured using an acceleration sensor. All hardware is equipped with a bluetooth module that allows data to be transmitted wirelessly.



Stacking board Cone plate Wearable band

Figure 2. Examples of Hardware of the Prototype

2) Software design

Applications for android devices were developed by applying C# in the visual studio environment to manipulate hardware and collect performance data from patients. The application was developed as one-to-many communication with the stacking board, cone plate and wearable band. It was designed using the broadcast casting to transmit the location information of each hardware. The behavior information of the patients could be collected by the measurement variables and the data could be accumulated and managed by changing the form of string data to the software.

3) Measurement variables

Specific measurement variables have been established so that the patient's performance can be measured correctly using hardware and software. The measurement variables are comprised of success, error, success rate, tremor, loading time, release time, and total time. The meaning of each measurement variable is presented in Table 1.

4) Contents of the evaluation modules

The evaluation contents of the prototype comprised the 'single task evaluation mode' and 'dual task evaluation mode' that could assess the upper extremity function and dual task performance of patients. Among the single task evaluation mode, the 'Single task module for stacking on the cones', named STS(e) mode, is an evaluation module in which the patient stacks the cone high in one fixed position with LED lights on the stacking board while the therapist presses the start button, and the operational definition of success was defined as a perfect score of 20 cones in 180 seconds through the focus group interview. the 'Single task module for putting on the cones mode', named STP(e) mode, is an evaluation module of inserting the cones into all positions of the stacking board, and the operational definition of success was defined as a perfect score when performing correctly 9 times within 80 seconds.

Among the dual task evaluation mode, the 'Dual task module for randomized putting on the cones', named DTRAN(e) mode, is an evaluation module in which the patient recognizes the location of the light

Table 1. The Meaning of Each Measurement Variables

Variables	Means
Success	Number of cone stacking in the correct location
Error	Number of cone stacking in the wrong location
Success rate[1)]	Percentage of the number of the success times of the total times
Tremor	Average hand tremor data from when the cone is lifted to laid down
Loading time	Average time from the cone is held on the cone plate to the cone is inserted on the stacking board
Release time	Average time from the cone is placed on the stacking board to the cone is held on the cone plate
Total time	Total patient's performance time

[1)]success/(success+error)x100

Table 2. Composition of Evaluation and Training Contents for Prototypes

Classification	Evaluation contents	Training contents
Single task module	STS(e) mode	STS(t) mode
	STP(e) mode	STP(t) mode
Dual task module	DTRAN(e) mode	DTRAN(t) mode
	DTRP(e) mode	DTRP(t) mode
	DTRR(e) mode	DTRR(t) mode

DTRAN=dual task module for randomized putting on the cones; DTRP=dual task module for remember the positions; DTRR=dual task module for remember the rules; STP=single task module for putting on the cones; STS=single task module for stacking on the cones

and reacts to it as quickly as possible to plug in the cone according to randomly lit LED of stacking board. The operational definition of success of DTRAN(e) was defined as inserting the cone into the correct position within 5 seconds per cone and performing it 9 normal times. the 'Dual task module for remember the positions', named DTRP(e) mode, is an evaluation module of remembering the 5 positions where LEDs turn on at the same time, and when all LED lights are turned off, 5 cones must be inserted in the correct position within 45 seconds. The operational definition of success of DTRP(e) was defined as inserting 5 cones into the correct position within 45 seconds and performing it 4 normal times. Finally, the 'Dual task module for remember the rules', named DTRR(e) mode, is performed by remembering the rule that should be plugged in or not be plugged in depending on the color of the LED (e.g. remembering the given rules such as plugging in the blue cone when the red light comes on). The operational definition of success of DTRR was defined as inserting the cone into the correct position within 5 seconds per cone and performing it 9 normal times (Table 2).

5) Contents of the training modules

Training content is comprised of the 'single task training mode' and 'dual task training mode', which is the same as the basic items of evaluation content, STS(t), STP(t), DTRAN(t), DTRP(t) and DRPP(t) modes. Training content includes the ability to reach, grasp, release, attention, memory and working memory, and training can be conducted with both hands or customized difficulty levels depending on the patient's ability to perform dual tasks. For example, the difficulty level can be adjusted through several methods such as expanding and reducing the number of connected stacking boards and cones applicable to training, changing the randomization level of LED color, and changing the total performance time.

2. Usability study

1) Participants

The general characteristics of participants in the usability test are shown in Table 3. The participants are comprised of four experts, including two clinical occupational therapists and two doctoral occupational therapists.

Table 3. General Characteristics of Participation

Participants	Sex	Department	Career period
1	Female	Research	5 years
2	Female	Research	2 years
3	Male	Rehabilitation hospital	3 years
4	Female	Rehabilitation hospital	3 years

2) Results of the usability of hardware and software

The results of collecting responses to the ease of use of hardware and software among the usability test areas showed the appropriateness of the product size, ease of adjusting wrist band size, ease of operating wrist band, ease of user registration and login process, ease of operating the evaluation and training menu, ease of manipulating and understanding the result menu, and the convenience of using the software (Table 4). The sum of the responses to all eight questions about usability of hardware and software resulted in very appropriate levels (34.38%), appropriate levels (40.63%), moderate levels (21.88%), and inappropriate levels (3.13%).

3) Results of the usability of evaluation and training modules

Among the appropriateness of the evaluation and training contents, since the bilateral training system and difficulty levels control system of the training mode were not reflected in the application of the prototype due to the limitations of the technical skills. Therefore, usability tests were conducted for the remaining feasible evaluation and training contents, except for functions that are not reflected. The usability test about contents module resulted in the appropriateness for upper extremity training, appropriateness for cognitive training, appropriateness for dual task training, interest in dual task training, and the most and least interesting items of dual task training mode (Table 5). The sum

Table 4. Results About Configurability of Hardware and Software

No.	Questions	Results				
		①	②	③	④	⑤
(1)	Is the size of the product appropriate?	0	0	2	2	0
(2)	Is it easy to adjust the size of the wrist band?	0	0	2	1	1
(3)	Is it convenient to operate a wrist band?	0	0	1	1	2
(4)	Is it easy to register and login?	0	0	1	2	1
(5)	Is it easy to understand the instructions that appear on the product?	0	0	0	1	3
(6)	Is it easy to manipulate and understand the evaluating and training menu?	0	0	0	3	1
(7)	Is it easy to manipulate and understand the results menu?	0	0	0	2	2
(8)	Is it easy to use the software?	0	1	1	1	1

① Very inappropriate; ② Inappropriate; ③ Moderate; ④ Appropriate; ⑤ Very appropriate

Table 5. Results About Appropriacy of Contents of Modules

No.	Questions	Results				
		①	②	③	④	⑤
		DTRAN		DTRP	DTRR	
(1)	Is it helpful for upper extremity training?	0	0	1	2	1
(2)	Is it helpful for cognitive training?	0	0	0	4	0
(3)	Is it helpful for dual task training?	0	0	0	2	2
(4)	Are the dual task items interesting?	0	0	1	2	1
(5)	What is the most interesting items among dual task menu?	0		1	3	
(6)	What is the least interesting items among dual task menu?	2		1	1	

① Very inappropriate; ② Inappropriate; ③ Moderate; ④ Appropriate; ⑤ Very appropriate
1) selected responses among DTRAN, DTRP and DTRR

of the responses of four of the six questions measured on a 5-point likert scale resulted in very appropriate level (25.00%), appropriate level (62.50%), and moderate level (12.50%). The response to the most interesting or least interesting items among dual task items, DTRR (75.00%) was selected as the most interesting item whereas DTRAN was selected as the least interesting item (50.00%).

4) Results of the applicability of prototype to patients

The results of collecting responses to patient applicability showed the identification of the patient's functional level and setting up a follow up training plan, degree of assistance in motivation, usability when compared to other rehabilitation devices, and applicability of this prototype to conduct dual task training (Table 6). The sum of the responses in the three questions showed very appropriate level (33.33%), appropriate level (33.33%), moderate level (25.00%), and inappropriate level (8.33%).

5) Results of the overall satisfaction

The results of collecting responses to the overall satisfaction, the results showed the ease of overall usage, satisfaction with overall product usage, and willingness to use when commercialized (Table 7).

Table 6. Results About Applicability of Prototype in Patients

No.	Questions	Results				
		①	②	③	④	⑤
(1)	Is it helpful to identify the patient's functional level, establish future training plans, and motivate them?	0	0	2	1	1
(2)	Is this prototype more useful than other rehabilitation device?	0	1	0	2	1
(3)	Is this prototype necessary for dual task training?	0	0	1	1	2

① Very inappropriate; ② Inappropriate; ③ Moderate; ④ Appropriate; ⑤ Very appropriate

Table 7. Results About Applicability of Prototype on Patients

No.	Questions	Results				
		①	②	③	④	⑤
(1)	Is it easy to use the overall product?	0	0	0	1	3
(2)	Are you satisfied with the overall use of the product?	0	1	0	1	2
(3)	Would you be willing to use it if it is commercialized?	0	1	0	1	2

① Very unsatisfied; ② Unsatisfied; ③ Moderate; ④ Satisfied; ⑤ Very satisfied

The sum of the responses in the three questions showed very satisfied level (58.33%), satisfied level (25.00%), moderate level (0%), and unsatisfied level (16.67%).

Ⅳ. Discussion

As a result of the usability test, the usability of the prototype was generally found to be at the appropriate level, and no response was showed to the very inappropriate levels for all items. This is interpreted by experts that the prototype has been well developed with appropriate design as a rehabilitation evaluation and training device. It is believed that clinical utilization may be expanded by incorporating ICT technology further from the traditional stacking cones.

Among the usability test, the areas with the highest level of adequacy and the lowest level of inadequacy were derived from ‘content adequacy’. Based on this, the evaluation and training contents of the prototype has been identified as occupational therapy tools that help evaluate and train upper extremity function, cognitive function and dual task performance. However, the bilateral training or difficulty level control system of the training mode were not reflected in the prototype due to technical limitations. Chan, Tong, and Chung (2009) reported that bilateral upper extremity training is more effective to improve upper extremity function than unilateral training, and Hong, Park, Kim, and Park (2020) reported that bilateral training is an effective approach for improving ADL performance. Therefore, it is necessary to develop the bilateral training contents and conduct usability tests to the therapists and the patients group to assess the adequacy of bilateral contents.

Additionally, the ‘overall satisfaction’ in the usability test is the area with the highest level of very appropriate level and the highest level of inappropriate level, so its results are considered unstable. When explore the sub-questions responses of the overall satisfaction area, the response to the contents of device usability was only distributed to the satisfaction level. However, dissatisfied responses were observed on the willingness to use when commercialized and satisfaction of overall product use. It is interpreted as a possibility of the overall satisfaction level may have been reduced due to the inappropriate level of response in the areas of hardware and software ease and patient applicability that the areas assessed prior to the overall satisfaction level. However, dissatisfied responses were observed on hardware and software usability and intention to use after commercialization. The acceptance of technology of device is also very important in terms of device usability (Yousafzai, Foxall, & Pallister, 2007), so it is necessary to clearly check the reliability of hardware and software. Also, it is necessary to assess whether clinical contents can be technically reflected by including technical experts in the focus group before commercialization.

Among the dual task contents, the most interesting content was the DTRR mode, while the least interesting content was the DTRAN mode. The DTRR mode is a task in which dual-task interferences are most exerted when performing upper extremity tasks among the three dual task modes, with rules given that cones should not be plugged in or plugged in depending on the color of the LED (National Rehabilitation Center, 2019). On the contrary, the DTRR mode is a task that is configured to have relatively less dual task interference than the DTRR, that remembers where LEDs are turned on (National Rehabilitation Center, 2019). Because participants who participated in this usability test are experts, it is believed that they responded from an expert's point of view, considering the dual tasks performance and the dual task interferences as they understood the purpose of developing this prototype correctly. It is necessary to assess the usability test after reflecting the bilateral training system and the difficulty grading system to check again the usability of finalized device.

This study has the following limitations. First, the focus group was only comprised of occupational therapists, it was a cause of the lack of technical feedback. Rehabilitation engineering experts need to be included in the focus group to ensure stability in device design when upgrading the device. Second, the usability test was conducted with the prototype because the study period provided to the device development was significantly short to complete the final device development. Since this has been tested for usability without high product completeness, future studies need to conduct usability tests after final product design development is performed. Additionally, more number of participants of usability test is required to compare the responses of the clinical group and the patient group. Also, applying the device to the patients is also considered necessary to identify clinical effectiveness.

V. Conclusion

This study aimed to introduce the process of developing the prototype of smart stacking cone using ICT for the evaluation and training of upper limb function and dual task performance of patients with central nervous system impairments. Also, the study aimed to present the results of the usability test of prototype. This prototype is significant in that it expands the choice of rehabilitation devices when therapists select evaluation and training methods. Additionally, it is cost-effective in that various evaluation and training content can be applied to clients with one device, and the performance of clients can be accumulated. We expect functional improvement of dual task performance skills of patients with central nervous system impairment and application of the ICT technology to rehabilitation devices.

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국문초록

ICT를 이용한 이중과제 기반의 스마트 스태킹 콘의 시제품 개발 및 사용성 평가

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목적 : 본 연구는 중추신경계 손상 환자의 상지기능과 이중과제 수행능력의 평가 및 훈련을 위해 개발 중인 스마트 스태킹 콘을 시제품 단계까지 개발하여, 사용성을 파악하고 수정 및 보완점을 점검하여 향후 연구 방향을 제시하고자 하였다.

연구방법 : 본 연구는 ICT 기술을 기반으로 ‘스마트 스태킹 콘’의 시제품을 개발하였으며, 평가 및 훈련으로부터 생성되는 피험자의 데이터를 관리할 수 있도록 하드웨어 회로 및 소프트웨어 기능을 설계하였다. 또한, 피험자의 수행을 올바르게 측정할 수 있도록 구체화된 측정변수를 설정하였으며, 이를 바탕으로 ‘단일과제 평가모드’, ‘이중과제 평가모드’, ‘단일과제 훈련모드’, ‘이중과제 훈련모드’로 콘텐츠를 구성하였다. 또한, 개발된 시제품의 임상적 적용 가능성과 전반적인 만족도를 평가하고자 사용성 평가를 실시하였다.

결과 : 사용성 평가 결과 개발된 시제품에 대해 전반적으로 보통 이상의 수준으로 긍정적인 응답이 나타났다. 특히, ‘콘텐츠 적절성’ 영역은 적절 수준이 가장 높게 응답된 영역이자 부적절 수준이 가장 저조하게 나타난 영역으로 확인되었고, ‘전반적 만족도’ 영역은 매우 적절 수준이 가장 높게 나타난 영역임과 동시에 부적절 수준 또한 가장 높게 나타난 영역으로, 기기에 대한 전반적 만족도는 안정적이지 못한 것으로 나타났다.

결론 : 본 연구 결과를 바탕으로 기기를 수정하여 완성한 후 실제 환자군에게 적용해봄으로써, 기기의 임상적 효과성을 파악하기 위한 연구가 진행되어야 할 것이다.

주제어 : 개발, 사용성 평가, 상지기능, 스태킹 콘, 이중과제