의학박사 학위 논문

Development and evaluation of mobile program for post-stroke aphasia and upper limb dysfunction

뇌졸중 환자의 실어증 및 상지 기능 회복을 위한 모바일 프로그램의 개발 및 유효성 검증

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서울대학교 대학원

의학과 재활의학 전공

최윤희

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지도교수 백 남 종

이 논문을 의학박사 학위논문으로 제출함

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최윤희

최윤희의 의학석사 학위논문을 인준함.

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Development and evaluation of mobile program for post-stroke aphasia and upper limb dysfunction

by
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(Directed by Nam-Jong Paik, MD, PhD)

A Thesis Submitted to the Department of Medicine in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Rehabilitation Medicine at the Seoul National University College of Medicine

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Abstract

Development and evaluation of mobile program for post-stroke aphasia and upper limb dysfunction

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Stroke rehabilitation requires repetitive, intensive, goal-oriented therapy. We designed home-based mobile rehabilitation programs as a way of u-health service for aphasia and upper limb function recovery that increased the hours of repetitive goal-oriented tasks without increasing costly therapy time or requiring expensive equipment.

Experiment 1. Mobile program for poststroke aphasia

A. A Tele-screening tool to detect aphasia in patients with stroke

We developed a valid, reliable Mobile Aphasia Screening Test (MAST) for patients suffering from stroke. To accomplish this, we enrolled patients with (n = 30) and without (n = 30) stroke-induced aphasia after stroke. To validate the MAST, we compared its performance to that of the Korean version of the Western Aphasia Battery (K-WAB) and conventional shortened paper version (K-FAST). There was significant correlation between K-FAST and MAST. MAST also had a high correlation with K-WAB. Inter-rater reliability was very high. The test had high sensitivity and specificity with an accuracy of 0.930. The MAST is a valid and reliable tool for detecting aphasia in patients with stroke.

B. A Telerehabilitation Approach for Chronic Aphasia Following Stroke

We developed a telerehabilitation program for chronic aphasia following stroke that utilizes a mobile device (iAphasia). Eight patients received 4 weeks of telespeech therapy using iAphasia. After the 4-week treatment, language function as measured by the K-WAB was significantly improved. The improvement was persistent at the 1-month follow-up visit. The degree of improvement was strongly associated with usage time, regardless of participants' age and severity of aphasia. Overall, satisfaction with iAphasia was rated high. iAphasia is an effective and feasible treatment method for chronic aphasia.

Experiment 2. Mobile program for upper limb dysfunction after stroke

We developed a mobile game-based upper extremity virtual reality program using a smartphone and tablet PC for patients with stroke (MoU-Rehab) and evaluated the program's feasibility and effectiveness. This randomized, double-blind, controlled trial included 24 patients with ischemic stroke. The intervention group (n = 12) received 30 min of conventional occupational therapy (OT) plus 30 min of the MoU-Rehab. The control (n = 12) received conventional OT alone for 1 h per day. Rehabilitation consisted of 10 sessions of therapy 5 days per wk for 2 wk. A greater improvement in the FMA-UE, B-stage, and MMT was found after treatment with the MoU-Rehab than with conventional therapy. The amount of improvements in the MBI, EQ-5D, and BDI were not significantly different between the two groups. Patients in the experimental group completed the 2-wk treatment without adverse effects, and they were generally satisfied with the MoU-Rehab. The MoU-Rehab is feasible and effective for promoting upper limb recovery after ischemic stroke.

We developed programs for aphasia and upper limb recovery in patients with stroke. We gained scientific evidence for efficacy and feasibility of home-based mobile rehabilitation programs as a way of u-Health service.

Keywords: u-Health, mHealth, Stroke, Rehabilitation, Aphasia, Upper extremity, Telehealth, Telemedicine

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(shoulder/ elbow/ wrist)

(D) Change in the modified Barthel index

(E) Change in the EQ-5D index

(F) Change in the Beck depression inventory

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Introduction

Stroke is one of the most common causes of neurological impairment in adults. The recovery of impairment after stroke is usually incomplete and approximately 50% of patients are left with disabilities making them dependent on others.[1] Patients with stroke usually have motor impairments due to weakness, balance problems and poor general health. They frequently have difficulty traveling to a clinic or institute because of such disabilities, or sometimes even because of lengthy travel time. Many patients who live in distant locations, or who have transportation challenges, are undertreated or completely untreated. Moreover, socioeconomic difficulties and poor familial support can hinder patients' ability to get treatment. To remove these barriers, there has been increased interest in assistance from information and communication technologies (ICT) in the field of rehabilitation medicine. [2] Mobile devices such as smartphones and tablet PCs have enormous potential for personalized home therapeutic practice, as well as for interactive communication between patients and clinicians. Penetration of smartphones and tablet PCs into the general population is soaring. Therefore, the development of a ubiquitous healthcare (u-Health) program using mobile devices is requisite.[3]

We selected two patient groups as target populations. One group was composed of patients with poststroke aphasia. (Experiment 1.) Between 24 and 30% of the patients suffer from various types of aphasia following stroke, and the degree of recovery varies among patients.[4, 5] Aphasia is not only problematic for patients with stroke in daily life, but is also a key prognostic factor for their functional outcome. [6] Nevertheless, most patients who suffer from aphasia are underdiagnosed and undertreated because of socioeconomic difficulties, poor family support, lengthy travel time and motor impairments. Therefore, patients with post-stroke aphasia were thought to be a good candidate for u-health service. Another group was composed of patients with upper limb dysfunction after stroke. (Experiment 2) Upper limb dysfunction makes stroke survivors dependent for activities of daily living.[1] Regaining lost function in the upper extremities may be more difficult to achieve than returning normal function of ambulation to the lower extremities. Although bilateral lower extremity movement is indispensable for locomotion, patients can perform activities of daily living with unilateral upper extremity movement. This leads to a learned non-use

phenomenon of the affected limb.[7] This phenomenon is an obstacle to rehabilitation of the upper extremity in stroke survivors. Therefore, extensive practice and repetitive task-specific training is mandatory.[8-10]

Experiment 1. Mobile program for poststroke aphasia

A. A Tele-screening tool to detect aphasia in patients with stroke

The greatest amount of spontaneous recovery in aphasia occurs in the first 3 months following stroke, but then the rate of recovery slows, and little additional spontaneous recovery can be expected after the first 1 year.[11, 12] Speech therapy for aphasia effectively promotes the recovery of functional communication, receptive language, and expressive language.[13] However, the effectiveness of treatment is expected to be lesser in the chronic stage than in the acute stage.[14] Therefore, identifying a candidate for treatment of aphasia is a requisite. Many aphasia assessment tools have been introduced to date. However, most of them involve long testing times, and their administration requires a speech and language therapist. Moreover, many screening tools need to be administered face-to-face by a health-related professionals, if not by a specialized speech and language therapist. Patients who have had a stroke usually have motor impairments due to weakness, imbalance, or poor general condition, and have difficulty visiting a clinic or an institute because of their disabilities. Many patients who live in rural or

urban locations with inadequate transportation cannot be identified and assessed, and therefore remain undiagnosed. To circumvent these obstacles, a screening tool that can be used by non-specialists, such as caregivers, and administered anywhere, is required. Therefore, a readily available, simple, and quick screening tool is necessary to identify patients with potential language problems. As a result, there has been an increasing demand for information and communication technologies in the field of speech and language rehabilitation.[2]

At present, the Frenchay Aphasia Screening Test (FAST) is the most widely used, and thoroughly evaluated, screening test for aphasia after stroke.[15, 16] It is brief, easy to administer, and has a good reliability in identifying patients with language problems, even when used by a non-specialist.[16] It is suitable for use by general practitioners, junior medical staff, and other non-specialists.[17, 18] The FAST is made up of 4 subscales: comprehension, verbal expression, reading and writing. To reduce administration time, the shortened version of FAST, with only the comprehension and expression sections, can be administered. The classification sensitivity of the shortned FAST is reported to be similar to that for the complete version.[19] A significant inverse relationship between FAST score and age has been reported.[18] The stratified cut-offs and normative data are available for both

the complete and shortened version of the FAST for two age groups (≤64 years and ≥65 years).[20] To administer the FAST, double-sided stimulus card with attached reading cards, pencil, paper and stopwatch are required. Thus, developing a mobile version of the FAST is the need of the hour; a mobile version would not require these tools, and the test could be administered anywhere and anytime without time and space restraints.

We developed a Mobile Aphasia Screening Test (MAST) for patients with stroke, with an emphasis on cost-effectiveness, portability, and ease of use. We accomplished this by modifying the Korean language version of the FAST (K-FAST)[21] as a mobile version. The items of MAST are identical to those of the shortened version of K-FAST. In this present study, we report the validity and reliability of the MAST.

Methods

Participants

We recruited stroke patients with (n = 30; test group) and without (n = 30; control group) aphasia as diagnosed and confirmed by a trained physiatrist. Patients with stroke without aphasia were age-matched with those with aphasia. The presence of visual field defects, visual neglect or inattention,

illiteracy, deafness, poor concentration, or confusion negatively affects the specificity of FAST.[17, 22, 23] Therefore, we excluded patients with such issues in this study.

Procedures

Tele-screening system design

The MAST uses a client-server model in which all data are stored in a central server. The iPad (Apple, Cupertino, California) mobile application was designed and implemented in order to improve the ease of use of the model. We developed a web portal for service providers, such as therapists and assessors, with accessibility to, and management of the data. The client program and server system communicated over the network with a Hypertext Transfer Protocol Secure (HTTPS) in order to ensure secure communication. The central server consisted of several layers of supportive servers in order to support efficient development of the mobile- and web-applications. The supportive servers are as follows: the open application programming interface (API), which acts as a gateway between the mobile application and the central storage; the controller layer, which provides a web service for providers; the data access layer, which provides queries to access the underlying database; and the database server in the persistence

layer. We implemented all the server programs on a Java platform (Figure 1).

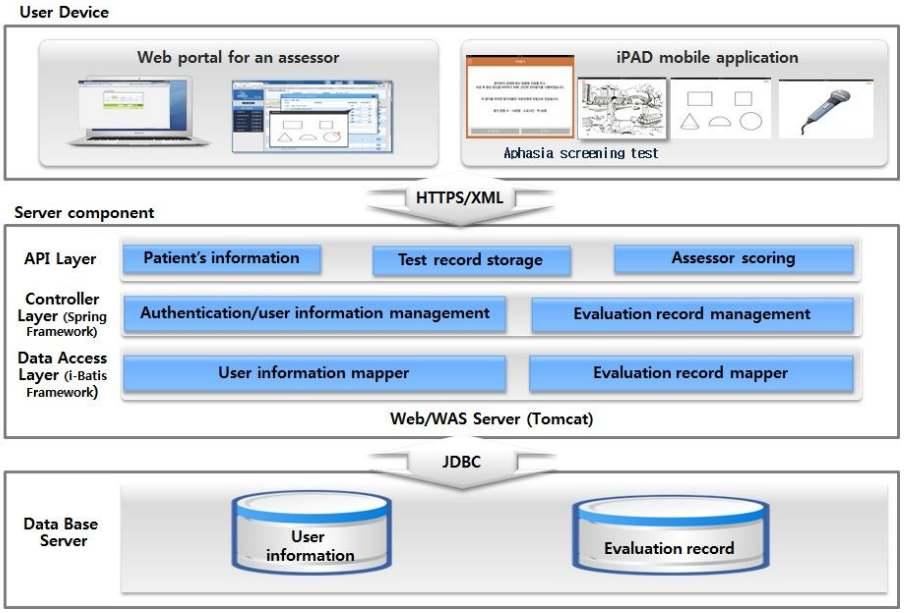


Figure 1. System architecture of tele-screening system for aphasia in stroke patients.

We designed the iPad mobile application, which includes a MAST, to be user-friendly and easy to use by using big letters, having minimum user options, and by providing step-by-step voice-guided directions. Patients who had no experience using any mobile device were educated to answer through their finger movement on the touch screen. The patients' records, such as voice recording and the touch pattern on each item, were then automatically sent to, and stored in, the central database through the open API (Figure 2).

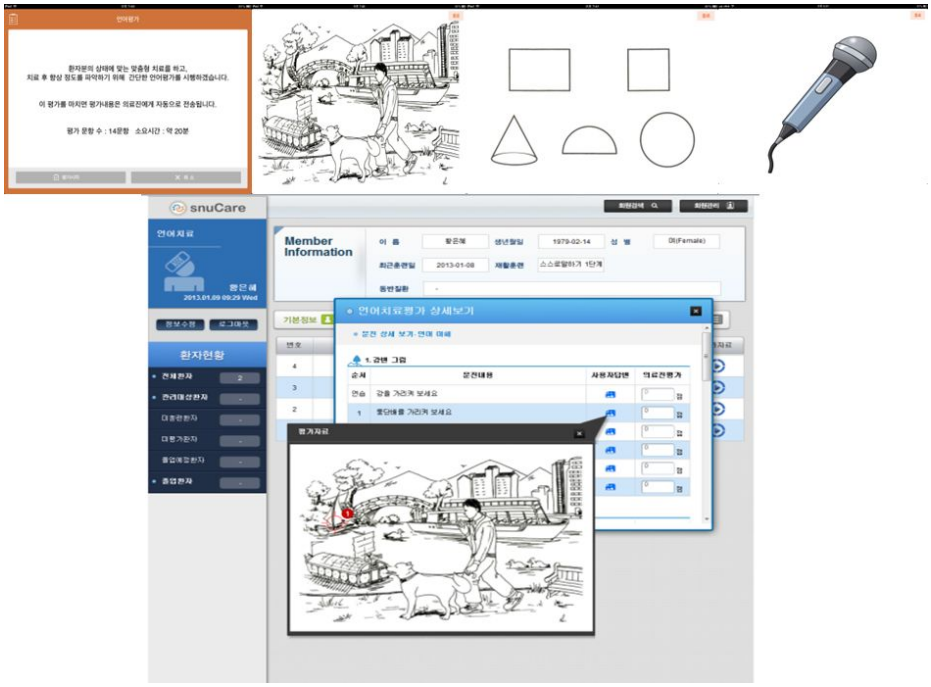


Figure 2. iPad application for aphasia screening test and web portal for scoring.

Test administration

A research assistant (RA1), who is not a speech and language therapist, administrated the MAST. A well-trained speech and language therapist (ST1) scored the patient's response on a K-FAST tool. To assess the comprehension function, we asked the subjects to respond by choosing the appropriate item from among the many, displayed on the screen, using their

fingers. This test had 10 questions with the pictures of river scenes and shapes. The system automatically scored the responses, and the scores were saved in a web portal. To evaluate their verbal expression, we asked the subjects to describe the picture of a river scene, and name as many animals as possible, in one min. Two assessors [a well-trained speech and language therapist (ST2), and a research assistant (RA2)] scored the verbal expression section by listening to the patient's recording stored in the web portal. A total combined score of the K-FAST and MAST is 20. In addition, K-WAB was administered to patients with aphasia to obtain the ROC curve. Our team chose the Korean version of the Western Aphasia Battery (K-WAB), because it is a validated method that is accepted as the gold standard and is capable of reliably discriminating between individuals with or without aphasia.

Statistical Analysis

We assessed the concordance of the K-FAST and MAST by calculating the intraclass correlation coefficient (ICC) from the score of each item and the total scores. We determined the correlation between the MAST and K-WAB

by Pearson's correlation coefficient. Only patients with a diagnosis of aphasia were evaluated by the K-WAB.

Inter-rater reliability was determined using the Pearson correlation and intraclass correlation coefficient (ICC), to evaluate the consistency of measurements on the same patient by different raters and to determine the extent to which the raters are interchangeable. To evaluate external validity, we assessed sensitivity and specificity using cut-off values from Pyun et al.[20] The diagnostic accuracy power was analyzed through the receiver operating characteristic (ROC) curve, and the area-under-the-curve (AUC) with 95% confidence limit was measured.

We calculated Cronbach coefficient alpha, a measure of reliability based on internal correlation of the items on the scale. In addition, we calculated the correlations between the score obtained on individual items (item-item correlations), and between the scores obtained on each individual item and the total score (item-total correlations).

Results

We enrolled 30 patients with stroke and aphasia (25 males and 5 females; mean age: 53.67 ± 15.27 years [range: 21–77]) for this study. They had either an ischemic (n = 21) or a hemorrhagic (n = 9) stroke. The lesion location was either to the left (n = 26) or bilateral (n = 4). The onset-to-assessment intervals for the patients with stroke and aphasia ranged from 2 to 2736 days, with a mean of 413.7 days. The average Aphasia Quotient (AQ) of K-WAB was 49.89 ± 25.22 [range: 5–96.9]. We also recruited 30 stroke patients without aphasia (22 males and 8 females; mean age: 53.90 ± 14.54 years [range: 21–79]) for the control group. They had either an ischemic (n = 20) or a hemorrhagic (n = 10) stroke. The lesion location was on the left (n = 11), right (n = 18) or bilateral (n = 1). The onset-to-assessment intervals for the patients without aphasia ranged from 3 to 8128 days, with a mean of 925.3 days. The age (t = 0.765), sex (t = 0.064), type of stroke (t = 0.204) and stroke location (t = 0.794) were comparable between both the groups.

Equivalence of the K-FAST and MAST: The comparison of the K-FAST and MAST in the sample of 60 patients with stroke showed that the two versions were strictly equivalent with an ICC total score of 0.995 ($p < 0.001$). The ICC scores for each comprehensive function assessed were 0.956 ($p < 0.001$) for the river scene and 0.980 ($p < 0.001$) for shapes. Likewise, tests on verbal expression had an ICC score of 0.997 ($p < 0.001$) for the "Description test" and 1.000 for the "Name test." None of the patient diagnosed as "aphasic" in one test was "non-aphasic" in the other test.

Concurrent validity assessed by comparing the scores with the K-WAB: The correlation between the total score of MAST and the aphasia quotient (AQ) of K-WAB was 0.752 ($p < 0.001$; Table 1). Given that the correlation between the total score of the K-FAST and the AQ of K-WAB was 0.737 ($p < 0.001$), the MAST could measure most part of the language function assessed by K-WAB. With regard to individual items (river scene; shapes: comprehension, description; fluency and name: naming), the item-item correlation score from

the MAST was also similar to the item-item correlation between the scores from the corresponding section of the K-FAST and K-WAB tests. Therefore, MAST could predict the result from the K-WAB as well as K-FAST.

Table 1. Concurrent validity of MAST with K-WAB (n = 30)

	Total score	River scene	Shapes	Describe	Name
AQ	0.752*	0.782*	0.546†	0.610*	0.641*
Auditory comprehension	0.477†	0.645*	0.232§	0.403‡	0.358‡
Fluency	0.648*	0.725*	0.421‡	0.514†	0.571*
Naming	0.649*	0.673*	0.394‡	0.616*	0.521†

AQ, Aphasia Quotient. K-WAB, Korean version of the Western Aphasia Battery ; MAST, Mobile Aphasia Screening Test.

* P < 0.001; † P < 0.01; ‡ P < 0.1; § no statistical significance

Inter-rater reliability: Inter-rater reliability of the MAST for all the 60 stroke patients was near perfect. (Total score, 11.68 ± 5.95 vs. 11.62 ± 5.90; r = 0.997, p < 0.001 and ICC = 0.999; p < 0.001; Table 2).

Table 2. Inter-rater reliability

	Comprehension		Verbal expression		Total score
	River scene	Shapes	Describe	Name	
r	0.977*	0.997*	0.997*	0.984*	0.997*
ICC	0.988*	0.998*	0.999*	0.992*	0.999*

r, Pearson correlation coefficient; ICC, Intraclass Correlation Coefficient

* $P < 0.001$.

Diagnostic sensitivity and specificity: Taking the diagnosis by an experienced physiatrist as the gold standard, and using the cut-off points for K-FAST from Pyun et al.[20] (16 for ≤ 64 years and 14 for ≥ 65 years), the sensitivity (detection rate of abnormal values in aphasic patients) of both MAST and K-FAST were 90.0%. The specificity of the test was 73.3% for MAST and 86.7% for K-FAST. In the aphasic group, the number of patients who had abnormal/normal values was the same for MAST and K-FAST (27/3), and in the non-aphasic group, they were 8/22 and 4/26 for MAST and K-FAST, respectively. We evaluated the sensitivity and specificity of detecting aphasic patients by means of an ROC curve analysis (Figure 3). The area-under-the-curve with 95% confidence limit was 0.817 (0.703–0.931) for MAST. Compared to K-FAST, the diagnostic accuracy was not inferior.

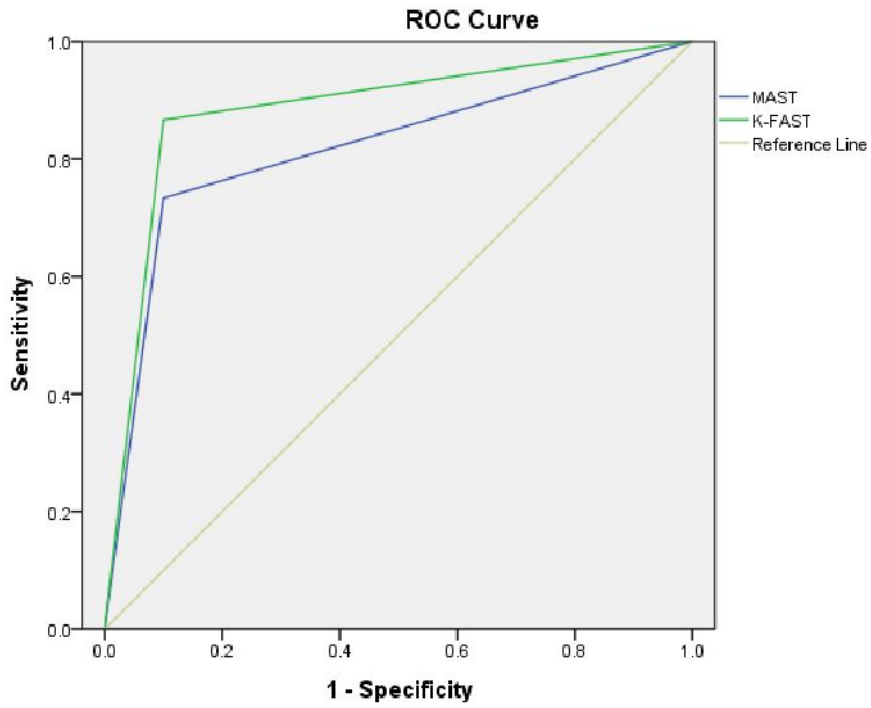


Figure 3. Receiver operating characteristic (ROC) curve showing the sensitivity (true-positive rate) and 1-specificity (false-positive rate) of the Mobile Aphasia Screening Test (MAST) versus the conventional Korean version of the shortened version of Frenchay Aphasia Screening Test (K-FAST).

Internal reliability: The internal consistency of the 15 items in MAST was good with a Cronbach α of 0.88 ($p < 0.001$). Table 3 shows the correlation between the scores obtained on each individual item (Item-item correlations), and between the scores obtained on each individual item and the total score (item-total correlations).

Table 3. Item-Item correlations and Item-Total correlations

	River scene	Shapes	Describe	Name
River scene				
Shapes	0.602*			
Describe	0.537†	0.662*		
Name	0.674*	0.809*	0.603*	
Total score	0.812*	0.890*	0.839*	0.888*

* $P < 0.001$

† $P < 0.01$

Discussion

We have developed and validated a mobile language-screening test for patients with stroke. The MAST has good internal validity, correlates well with the gold standard K-WAB, shows very high inter-rater reliability, and is quick to complete. We used the K-WAB to examine the validity of assessments because many clinicians consider it the gold standard for assessment. The present study showed that the MAST could predict the result from the K-WAB as much as from the K-FAST. Importantly, even a non-specialist can administer the MAST. It showed excellent sensitivity and specificity for aphasia, thus identifying patients warranting a thorough

evaluation and treatment with a speech and language therapist.

The use of a tele-screening test can solve the problems faced by remotely situated patients, such as transportation, time, cost, caregiver availability, and stroke impairment. Users only need to download the application on a mobile device and use briefly with ease. The conventional FAST requires double-sided stimulus card with attached reading cards, pencil, paper, and a stopwatch or a watch with a second's hand. Therefore, it is usually available in a clinical setting only. However, mobile language screening test does not require any special equipment or stimulus cards and are available anywhere. We found that administration of the MAST was feasible and applicable to stroke patients. All participants easily adapted in using this iPad application regardless of age, after a brief introduction. Although most subjects had no experience in using a mobile device before, no one complained of difficulty in using it.

The demands of identification of candidate patients for aphasia treatment could be mitigated by using information and communication technologies. Use of mobile device-based decision-making in screening, diagnosis, and the planning of treatment are rare. Furthermore, the quality of the mobile device-based or PC-based applications that are currently being developed remains poor.[2] The present study included an innovative approach for developing a

ubiquitous tool for an aphasia-screening test along with the performance of a validation and reliability analysis.

Previous studies have evaluated the efficacy and feasibility of aphasia assessment methods only in a single subject or only in aphasia groups.[24-26] The present study is the first to report evidence showing that a tele-health service employing a mobile device can be used to differentiate between patients with aphasia who are candidates for intensive speech therapy, and patients without definite language problems.

Though the correlation between the conventional test and the mobile one was quite high, it was not 100%. The disagreement between the two tests could be due to the following reasons. The iPAD used a resistive screen with a touch input. Therefore, in some case when the subjects touched the device twice instead of once, or when our subjects responded early before the item-tasks presentation was completed by the system, the responses were considered wrong. In addition, the device was not sensitive enough to recognize subjects' finger touch on the screen. Therefore, even though our subjects responded accurately, the application perceived it as a wrong response. The automatic scoring system in the program workflow did not allow the subject to change their response. In order for the MAST to be on par with conventional test perfect for clinical utility, these usability errors

must be rectified.

B. A Telerehabilitation Approach for Chronic Aphasia Following Stroke

It was reported that patients improved by 73% of their maximum potential recovery (defined as their maximum potential language score minus their initial WAB score) during the first 90 days post-stroke.[27] There is a strong relationship between the intensity of aphasia therapy and subsequent recovery, so providing high intensity aphasia therapy to patients in the chronic phase is essential for maximal recovery.[28] We targeted chronic patients rather than acute patients in the present study because spontaneous recovery in acute patients is considerable, making it hard to discriminate between spontaneous recovery and a treatment effect.

We developed a telerehabilitation program for chronic aphasia following stroke that is usable on a mobile device. In addition, we evaluated the feasibility and effectiveness of this telerehabilitation program in chronic aphasia therapy.

Methods

Participants

Patients who were diagnosed as exhibiting an post-stroke aphasia by an experienced physiatrist and speech-language pathologists (SLPs) were recruited. Patients were excluded from the study if they had visual field defects, visual neglect or inattention, illiteracy, deafness, poor concentration, or confusion. All patients participated in an individualized, home-based 4-week aphasia treatment program.

Procedures

The telespeech therapy program (iAphasia) was developed on the iPad (Apple, Cupertino, California) as a mobile application with an emphasis on ease of use. Although the application provided step-by-step, voice-guided directions to allow for more intuitive use, patients with no experience using any mobile device were given additional education on how to use the program by finger movements on the touch screen. The patients' recorded results, such as voice recordings and the touch patterns on each item, were then automatically sent to and stored in a central database. Service providers (e.g., physiatrists and SLPs) could access the data via a web portal. Subjects were asked to participate in the mobile aphasia screening test (MAST), which adopted the Korean version of the shortened version of the Frenchay Aphasia Screening Test (K-FAST) described previously. [29] This was

included in the application prior to beginning the speech therapy program. The system automatically scored the response and saved the results in a database accessible via a web portal. The SLP determined the recommend step in each domain (6 domains; auditory comprehension, reading comprehension, repetition, naming, writing, and verbal fluency) which subjects would carry out in the speech therapy program. All domains were divided into 6 difficulty steps (Figure 4).

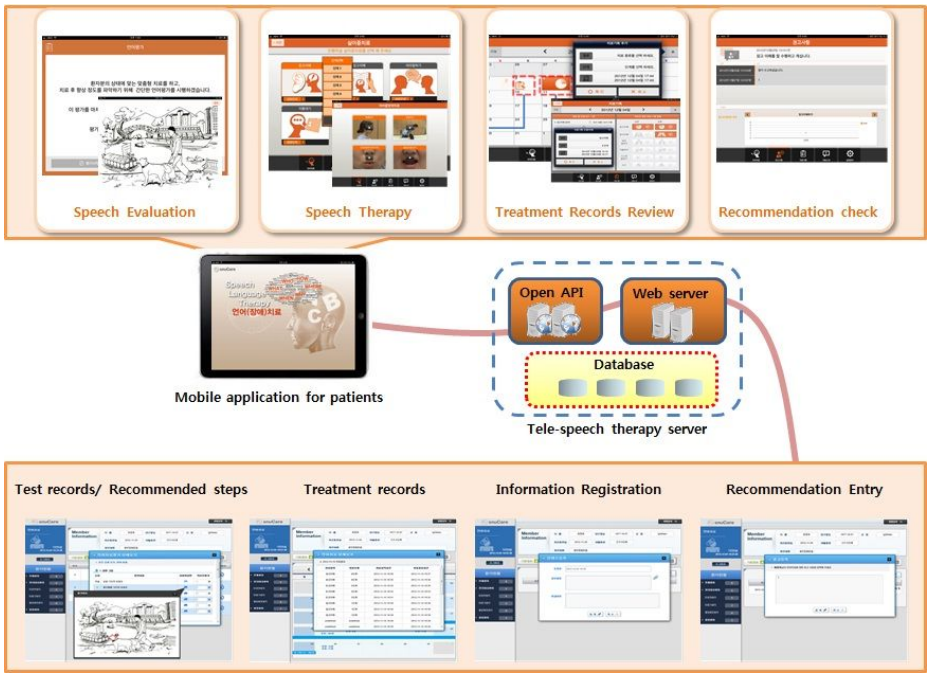


Figure 4. System architecture of tele-speech therapy program for patients with chronic aphasia following stroke.

API, application programming interface

The SLP also suggested to patients the most suitable step in each domain for particular types of deficits, and particular levels of severity. Subjects performed the speech therapy program at the given step in each domain. Subjects were asked to participate in speech therapy using iAphasia as often as possible, and for as long as possible. The SLP provided feedback to patients after checking the duration of program usage and the patient records stored in the central database. After completing the 2-week treatment period, the patients were asked to carry out the evaluation program again, to determine the recommended post-treatment step in all domains by the SLP. To evaluate the effectiveness of the iAphasia program, the Korean version of the Western Aphasia Battery (K-WAB) was administered before and after the 4 week-speech therapy program. Four weeks after the completion of the treatment, patients were assessed again to determine long-term treatment efficacy (Figure 5).

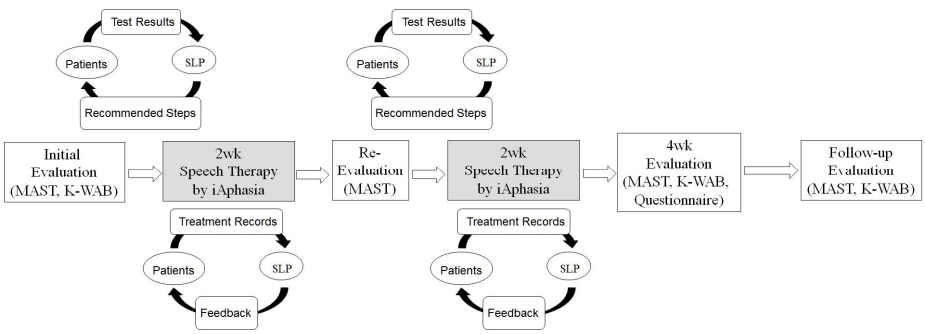


Figure 5. Treatment and evaluation flow

The iAphasia program

The telespeech therapy program for patients with aphasia using iPad (iAphasia) consisted of 6 therapeutic domains: auditory comprehension, reading comprehension, repetition, naming, writing, and verbal fluency. Each domain had 6 levels of difficulty (steps) organized in a hierarchy according to assumed task difficulty and language complexity. All sections started with a sample instruction, and had hints provided in addition. Picture- or text-based tasks were also available, enabling use by individuals whose difficulties included impaired comprehension or lack of speech (Table 4).

Table 4. iAphasia Contents

iAphasia domains	Tasks
Auditory comprehension	picture identification, auditory Yes/No questions, and auditory direction following
Reading comprehension	word-word matching, word-picture/picture-word matching, phrase-picture/picture-phrase matching, sentence-picture/picture-sentence matching, sentence completion, written Yes/No questions, Wh-questions, related words, and paragraph comprehension

Repetition	one/two word, phrase, and sentence repetition
Naming	picture naming, sentence completion, opposite meanings, association, proverb completion, and divergent naming
Writing	word/phrase copy, word/phrase/sentence completion, picture naming, dictation, complex multiple directions, phrase title decision, and question response
Verbal Fluency	verbal phrase/sentence completion, naming from description, picture description, verbal problem-solving, verbal reasoning, Wh-questions, number counting, and singing.

Questionnaire

As part of the feasibility assessment, we quantified user satisfaction with the treatment program by questionnaire. Both participants and caregivers responded to the questionnaire with guidance by a research assistant.

Statistical analysis

The sample size calculation based on previous literature using K-WAB as an outcome measure showed that 8 participants would be needed ($\alpha<0.05$, two-sided, power=80%).[30] All pre- and post-speech therapy measures were

compared using nonparametric statistics (e.g., Wilcoxon's signed-rank test) due to the small sample size. Comparisons included pre- and post-K-WAB subsection scores and the K-WAB Aphasia Quotient (AQ). The percentage increases from baseline in the K-WAB AQ were also compared, because baseline scores differed substantially between participants. We correlated program usage time and the change of K-WAB AQ score using Pearson's correlation analysis. All statistical analyses were carried out with SPSS 18.0 for Windows. A value of $p<0.05$ was considered statistically significant.

Results

Eight patients with chronic post-stroke aphasia (4 males, 4 females) ranging in age from 37 to 62 years (mean age 50.75 years) were recruited. Of these, 4 patients had suffered left middle cerebral artery infarction, and 4 patients had experienced left basal ganglia intracerebral hemorrhage. The mean time since stroke onset was 30 months (range 2 month -90 months). All patients were right-handed. Demographic characteristics of the eight patients who completed the study are presented in Table 5.

Table 5. Demographic characteristics of study participants

Subject	Age	Sex	Years of education	Post-stroke duration	Stroke Type	Baseline evaluation		Type of Aphasia
						K-FAST	K-WAB AQ	
1	51	M	16	90mo	Lt. MCA infarct	5	39.2	BA
2	56	M	11	22mo	Lt. BG ICH	1	45.0	MTA
3	62	M	17	39mo	Lt. BG ICH	6	63.8	WA
4	37	F	16	17mo	Lt. MCA infarct	7	46.0	WA
5	56	F	12	30mo	Lt. BG ICH	12	88.0	WA
6	41	M	16	26mo	Lt. MCA infarct	8	89.2	AA
7	45	F	16	2mo	Lt. MCA	8	29.6	GA

					infarct			
8	58	F	9	12.5mo	Lt. MCA infarct	15	83.0	BA

K-FAST, Korean version of the shortened version of the Frenchay Aphasia Screening Test; K-WAB, Korean version of the Western Aphasia Battery; AQ, aphasia quotient; MCA, middle cerebral artery; BA, Broca's aphasia; BG, basal ganglia; ICH, intracranial hemorrhage; MTA, mixed transcortical aphasia; WA, Wernicke's aphasia; AA, anomic aphasia; GA, global aphasia

Outcome measures

Baseline K-WAB scores indicated 50% (4) of the patients had severe, 12.5% (1) moderate, and 37.5% (3) mild aphasia. After the 4-week treatment, mean K-WAB AQ scores were significantly improved compared to the baseline scores, from 60.48 ± 23.78 to 69.68 ± 17.28 ($p = 0.022$). K-WAB subsections including fluency, auditory comprehension, and naming scores were also significantly increased after treatment. At the 1 month follow-up evaluation, those improvements that were significant were successfully maintained (Tables 6, 7).

Table 6. Korean version of the Western Aphasia Battery (K-WAB) Aphasia Quotient (AQ) change

Subject	Usage time* (min)	1month K-WAB AQ	Change of K-WAB AQ (raw score/ percentage†)	2month K-WAB AQ
1	689	43.8	4.6/ 11.7%	44.6
2	4744	64.2	19.2/ 42.7%	56.6
3	1491	73.2	9.4/ 14.7%	73.8
4	4342	64.0	18/ 39.1%	65.0
5	562	87.6	-0.4 /-0.5%	87.6
6	579	91.2	2.0/ 2.2%	91.2
7	1397	50.2	20.6/ 69.6%	56.4
8	728	83.2	0.2/ 0.2%	87.1

* Time spent using the iAphasia program

† Change of AQ defined as ((AQ at 1 month - AQ at baseline)/baseline)*100 (%)

Table 7. Korean version of the Western Aphasia Battery (K-WAB)

subsection change

K-WAB subsection	Pretreatment	Posttreatment	Change of the absolute values Change of percentage ((1 month – baseline /baseline)x 100) (%)	*p**	1month follow-up mean	*p†*
Fluency	12.06 ± 3.81	13.44 ± 2.99	1.38 ± 1.38 15.00 ± 16.39	0.039	13.69 ± 3.29	0.487
Auditory Comprehension	127.75 ± 54.65	152.88 ± 36.03	25.13 ± 23.45 31.82 ± 37.57	0.028	153.25 ± 37.55	0.888
Repetition	52.88 ± 43.87	68.37 ± 33.32	15.50 ± 25.33 8.70 ± 19.76	0.398	67.75 ± 33.99	0.677
Naming	56.13 ± 26.57	69.00 ± 16.23	12.88 ± 16.40 46.85 ± 73.61	0.075	70.00± 19.00	0.781
Reading	65.25 ± 30.22	72.00 ± 23.13	6.75 ± 11.96 30.31 ± 52.05	0.225	76.94 ± 21.93	0.056
Writing	52.94 ± 30.28	64.75 ± 28.31	11.81 ± 18.28 37.26 ± 70.27	0.116	65.69 ± 28.46	0.550
AQ (Aphasia Quotient)	60.48 ± 23.78	69.68 ± 17.28	9.20 ± 8.89 22.49 ± 25.38	0.022	70.29 ± 17.32	0.676

*Wilcoxon signed rank test –pretreatment vs posttreatment

† Wilcoxon signed rank test –posttreatment vs 1 month after completion of treatment

The mean program usage time over the 4-week period was 1816.50 ± 1723.44 (minutes). Program usage time correlated strongly and positively with improvement in K-WAB scores (*rho*: 0.861, p=0.006). For example, the 4 patients who spent more than 1397 minutes on the program demonstrated an 9.4 – 20.6 (average 16.8) improvement in their K-WAB AQ scores. The percentage of those 2 patients who used the program for more than 4342 minutes increase from baseline in the K-WAB AQ ([K-WAB AQ measured at 1 month – K-WAB AQ measured at baseline]/K-WAB AQ measured at baseline * 100) was 40.9% (see Table 6).

Questionnaire

All satisfaction items had a mean score above 4 on a 5-point scale (higher values equal greater satisfaction; see Table 8), even though most patients were not used to using smartphones or tablet PCs (never used 4/8 (50%), sometimes experienced 3/8 (37.5%)). Overall, the mean satisfaction scores were 4.88 ± 0.35. In particular, two participants who used the app for more than 4000 minutes responded more positively on the questionnaire.

In addition, patients who used this program stated that this program was highly motivating and enjoyable. Some patients remarked that they felt more confident about their communicating abilities. Also, patients' caregivers

positively commented on the program. They noted that the greatest advantage of the program was the convenience.

Table 8. User satisfaction survey results regarding the telespeech therapy program

Item	Mean
Telespeech therapy program provides sufficient treatment for me.	4.38 ± 0.74
The display of program is adequate.	4.13 ± 0.64
The program has good readability.	4.00 ± 0.76
It is convenient to use the program.	4.25 ± 0.71
Tele-speech therapy program provides on target services to you.	4.25 ± 0.71
In general, I am satisfied with the telespeech therapy program.	4.13 ± 0.64
The telespeech therapy program helps me to better manage my health and medical needs.	4.38 ± 0.52
How much (US dollars) are you willing to pay for this program? (1, strongly disagree to 5, strongly agree)	$25 ± 20 ($10-70)

Discussion

Our data support the development of iAphasia as a mobile device app with therapeutic utility that has the potential to reach underserved or neglected populations of patients with post-stroke aphasia.

To our knowledge, there is no scientific literature on the development of a rehabilitation application that can be used in a mobile device for the treatment of chronic aphasia. In general, rehabilitation therapy needs to be provided intensively, and in an easy-to-access format, when needed.[31] Telespeech therapy programs can dramatically improve access to speech therapy services for those who are underserved.

The degree and rate of improvement may be different for various facets of language. For example, the increase in K-WAB AQ was 22.49%. Among the subscores, naming improved most (46.85%), followed by writing (37.25%), auditory comprehension (31.82%), and reading (30.31%). This is different from the report by Ferro et al., who reported that comprehension recovered most rapidly.[12] However, Pedersen et al. reported no significant differences in recovery across subscores of the WAB, and found that gains ranged from 54% for comprehension to 78% for naming. [32]

In patients with chronic aphasia, it is known that there is no significant

change of WAB score in repeated evaluations with a certain time interval.[33] Also, considering Kats and Wertz define “clinically significant” changes on the WAB AQ as at least 5 points improvement, improvements in 4 patients (9.4-20.6) were sufficiently meaningful.[33, 34]

The most powerful predictor of recovery after stroke is the initial severity of aphasia, such that greater severity is associated with poorer recovery. [12, 32] However, the results in this study demonstrated that improvement was strongly and positively associated with program usage time, regardless of the initial severity. In addition, the improvements were not associated with the participant’s age or duration of aphasia. Meta-analysis revealed the average effect size of treated patients was smaller, but still exceeded that of untreated patients.[14, 35, 36]

We did a 1-month follow-up assessment to investigate the long-term effectiveness of the telespeech therapy program. The data suggests the improvements after a 4-week period could be maintained for a second month, suggesting the effect is not a transient one.

This study had a few limitations. The severity of aphasia in the participants was diverse (K-WAB AQ (%ile) range 21-88). An AQ score above 93.25 in the 15-47 year age group, and above 88.30 in the 75 or older age group, is considered normal (nonaphasic). [37] Patients with mild aphasia (patient

numbers 5, 6, and 8) were also enrolled in this study, and demonstrated zero or only minimal change in their K-WAB AQ scores. Unfortunately, the K-WAB may not be sufficiently sensitive for the detection of improvement in patients with mild forms of aphasia due to a 'ceiling effect'. However, we noted that this program was not attractive to patients with mild aphasia, and they spent little time (562-728 minutes) using the program. Thus, this program may not provide significant treatment to patients with mild chronic aphasia. In addition, because the sole validated questionnaire about telemedicine service only covers video visit programs, we were forced to create our own. [38] Thus, the questionnaire used in this study was not validated, and there are no existing validated questionnaires that could have replaced it. Because the sample size in this study was small, a larger scale, randomized, and controlled study is necessary to clarify the effectiveness of this program. In addition, the participants were highly heterogeneous in terms of post-onset duration and initial severity of aphasia. Future studies should attempt to collect a more homogeneous cohort.

Experiment 2. Mobile program for upper limb dysfunction after stroke

Particularly, upper limb dysfunction makes stroke survivors dependent for activities of daily living.[1] Regaining lost function in the upper extremities may be more difficult to achieve than returning normal function of ambulation in the lower extremities. Although bilateral lower extremity movement is indispensable for locomotion, patients can perform activities of daily living with unilateral upper extremity movement. This leads to a learned non-use phenomenon of the affected limb.[7] This component is an obstacle to rehabilitation of the upper extremity in stroke survivors. Therefore, a tremendous amount of researches have been focused on upper limb function recovery. Studies have highlighted the importance of extensive practice and repetitive task-specific training. [8-10]

Recently, virtual reality (VR) technology has been introduced to the rehabilitation field. VR allows users to interact with a simulated environment and receive continuous, immediate feedback related to performance. VR has the potential to apply basic concepts of neurorehabilitation for stroke patients such as intensive, repetitive and task-oriented training.[39] Specifically, non-immersive VR does not require the highest level of graphics performance and no special hardware. Therefore, non-immersive VR can be

a good candidate to provide a low-cost, ubiquitous and interesting treatment program. Previous literatures used computer, monitor, special devices such as a console, sensor glove, joy stick or commercial gaming systems for non-immersive VR.[40] The higher start-up costs and sufficient space were mandatory. To enhance the popularity of non-immersive VR as a post-stroke upper extremity treatment method, portable and inexpensive tools should be used.

Also, game-based therapy can be a good option for stroke rehabilitation. Many patients complain that conventional occupational therapy (OT) for upper limb function recovery is boring and monotonous.[41, 42] A more interesting and motivating tool for therapy is necessary to promote patients' engagement in rehabilitation training. Currently, many studies which have been conducted used commercial games.[43-45] However, they do not target the desired movement of upper extremity in patients with stroke and they lack special consideration for spasticity after stroke.

Therefore, the objective of the present study was to develop a mobile game-based upper extremity VR program as a way of u-Health for patients after stroke and evaluate the feasibility and effectiveness of the program.

Methods

Participants

Participants who had (1) a diagnosis of ischemic stroke; (2) the ability to follow a one step command; (3) medical stability to participate in active rehabilitation and (4) upper extremity impairment were recruited. Patients were excluded if they (1) had delirium, confusion or other severe consciousness problems, (2) suffered from uncontrolled medical conditions, (3) were unable to follow command because of severe cognitive impairment, (4) had visual disturbance and (5) had poor sitting balance. To make participants completely blinded to group assignment, participants were assigned to either control or experimental group by admission period.

Procedures

All participants completed the rehabilitation program, which consisted of 10 sessions of daily therapy provided 5 days per week for 2 weeks. In both groups, the total treatment dose was matched as one hour per day. Patients who were allocated to the intervention group were treated using the mobile upper extremity rehabilitation program (MoU-Rehab). Patients in the intervention group received 30 minutes of conventional occupational therapy

(OT) plus 30 minutes of MoU-Rehab. Patients in the control group received conventional OT alone for one hour per day. Conventional OT including range of motion exercises, fine motor training, and strengthening exercises was delivered one-on-one to the patients by an occupational therapist. Patients in the intervention group were educated on how to use the MoU-Rehab in the first treatment session although each game application provided brief instructions at the beginning. Patients used the program for 30 minutes on their own during the study. The time spent on each application was not controlled and only the total treatment time per session was controlled. Physicians and occupational therapists in the rehabilitation unit were aware that a study was occurring but were unaware of the group assignment.

The mobile upper extremity rehabilitation program (MoU-Rehab)

The MoU-Rehab was developed using a combination of two mobile devices; a tablet PC (Galaxy Note 10.0, Samsung, Seoul, South Korea) and a smartphone (Galaxy S2, Samsung) with a Bluetooth connection. The MoU-Rehab consisted of mobile game applications. The patients' upper extremity movements were tracked by sensors built into the smartphone and information about the movement was transferred to the tablet PC through the

Bluetooth connection. Patients could get visual and auditory feedback on their movement by seeing the display in the tablet PC. During the game play, the smartphone was attached to the patients' forearm or upper arm using the arm band. The level of difficulty of the game applications was adjusted individually by the speed, maintenance time for the specific posture and range of motion according to the severity of upper extremity dysfunction. All game applications were designed to improve strength, endurance, range of motion, control, speed and accuracy of movement in the upper extremity. (Figure 6)

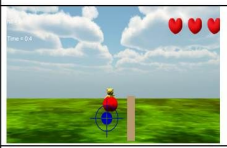
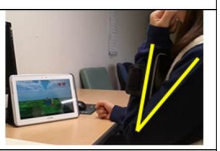
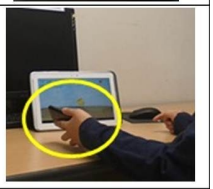
	Game application	Target movement	Activities
Honey Pot Guard		Elbow Flexion/ Extension	
Protect the Bunny		Shoulder Abduction/Adduction	
Put Out Fire		Shoulder Abduction/Adduction, Flexion/Extension	
Flower Splash		Shoulder Abduction/Adduction, Elbow Flexion/Extension, Wrist Pronation/Supination	

Figure 6. Game contents of the mobile upper extremity rehabilitation program

Outcome measure

All assessments were performed at the beginning, at the end of the treatment and at 1-month follow-up. A single blinded evaluator who is an experienced occupational therapist performed all of the clinical assessments during all the testing sessions. The primary outcome measure was the Fugl-Meyer Assessment of the upper extremity (FMA-UE), which measures motor function of the patients' hemiparetic arm (0 = lowest score; 66 = highest score).[46] The secondary outcome was evaluated by the Brunnstrom stage (B-stage) for the arm and hand, which evaluates the upper extremity recovery stages (1 = flaccid, no voluntary movements; 7 = normal function)[47]; manual muscle testing (0-5); modified Barthel index (MBI), which assesses the activities of daily living (0 = lowest score; 100 = highest score)[48]; EuroQol-5 Dimension (EQ-5D), which is a brief and standardized measure of health related quality of life[49]; Beck Depression Inventory (BDI), which is a self-rating mood scale (0 = lowest score; 63 = highest score, severe depression)[50] and program use-related complications.

Statistical Analysis

The independent *t*-test (for continuous variables) and chi-square test (for

categorical variables) were used to compare the baseline characteristics of subjects in the experimental and control groups. The paired *t*-test was used for within-group analyses, and repeated measures one-way analysis of variance followed by post hoc tests was used for between-group analyses. All statistical analyses were performed using SPSS 18.0 for Windows (IBM Corp., Armonk, NY). A value of $p<0.05$ was considered statistically significant.

Results

Two hundred seventy-two hospitalized patients in the Department of Rehabilitation were initially assessed for eligibility. One hundred fifty-one patients did not meet the inclusion criteria. Fifty-one patients declined to participate. Twenty-six patients were excluded because of a poor general condition. Finally, 24 patients were enrolled and assigned to either the control or experimental group. None of the patients in either group dropped out and reported significant adverse events associated with the study protocol. (Figure 7) The baseline characteristics of the patients are shown in Table 9. There were no statistically significant differences between the two groups except the with regard to age (experimental group: 61.0 ±15.2 years

vs control group: 72.1±9.9 years, p=0.046).

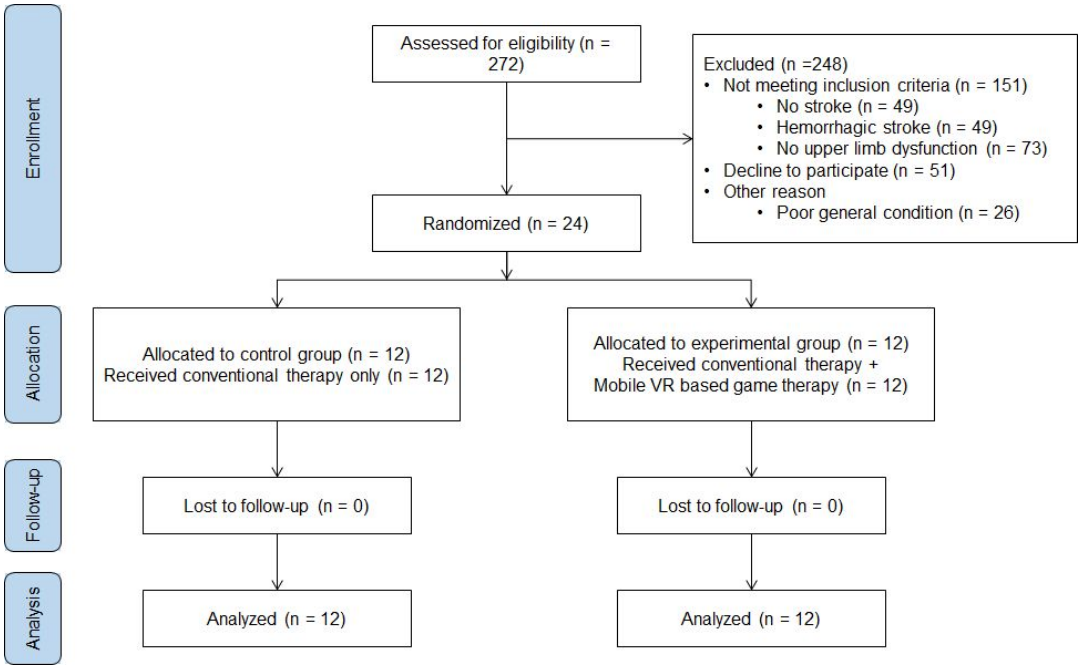


Figure 7. Flow chart of participants in the study with the Consort diagram for subject selection and assignment

Table 9. Baseline demographic and clinical characteristics of the patients

	Experimental group (n=12)	Control group (n=12)	p-value
Sex (M/F)	7/5 (58.3%/41.7%)	6/6 (50.0%/50.0%)	0.5 [a]
Age (years)	61.0±15.2 (21-76)	72.1±9.9 (53-88)	0.046 [b]
Affected limb (L/R)	8/4 (66.7%/33.3%)	10/2	0.32 [a]

		(83.3%/16.7%)	
FMA-UE (range)	24.5±22.2 (4-63)	21.5±20.6 (4-57)	0.735 [b]
Brunnstrom-stage (arm)	2.7±1.5 (1-5)	2.7±1.5 (1-5)	1.00 [b]
Brunnstrom-stage (hand)	1.9±1.4 (1-5)	2.1±1.4 (1-4)	0.775 [b]
MMT (shoulder)	2.7±1.1 (1-4)	2.2±1.2 (0-4)	0.292 [b]
MMT (elbow)	1.9±1.4 (1-5)	2.1±1.4 (1-4)	0.775 [b]
MMT (wrist)	2.7±1.1 (1-4)	2.2±1.2 (0-4)	0.292 [b]
Modified Barthel Index	2.5±1.1 (1-4)	1.8±1.5 (0-4)	0.219 [b]
EQ-5D index	2.0±1.2 (1-4)	1.4±1.4 (0-4)	0.282 [b]
Beck Depression Index	55.8±16.9 (32-83)	39.1±23.7 (4-88)	0.059 [b]

[a] χ^2 test, [b] t-test

FMA-UE: Fugl-Meyer Assessment of the Upper Extremity, MMT: Manual Muscle Test, EQ-5D: EuroQol-5 Dimension, M: male; F, female, L: left, R, right.

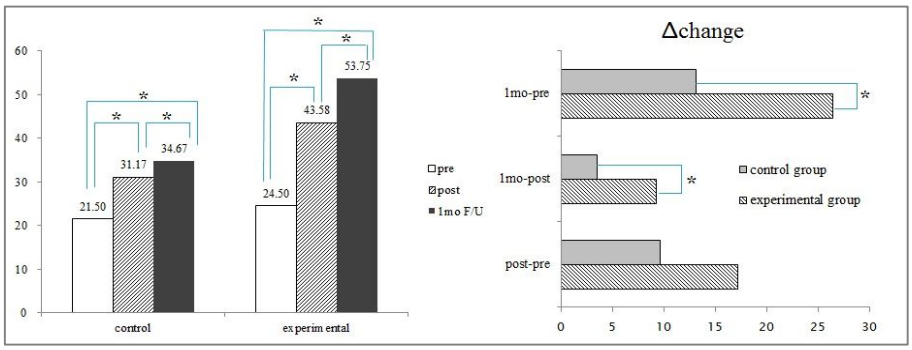
Outcome measures

Regarding the within-group changes, both groups showed significant improvements in the outcome measures related with recovery of the upper extremity such as the FMA-UE, B-stage, MMT and MBI. Also, health-

related quality of life measured by the EQ-5D index was improved after treatment in both groups. A depressive mood measured by the BDI was also reduced after treatment in both groups. Those effects lasted until the 1-month follow-up evaluation. (Figure 8)

For the between-group differences, the greater improvement was found in the experimental group than in the control group for upper extremity recovery measured by the FMA-UE, B-stage in the arm and the hand and MMT. Specifically, changes in the FMA-UE score ('pretreatment versus 1-month follow-up after treatment' and 'posttreatment versus 1-month follow-up after treatment') were significantly different between the two groups. (Figure 8-A) Also, significant greater changes in the B-stage in the arm ('pretreatment versus posttreatment') and the B-stage in the hand ('pretreatment versus 1-month follow-up after treatment' and 'posttreatment versus 1-month follow-up after treatment') were found in the experimental group. (Figure 8-B) Changes of motor power in the wrist ('pretreatment versus 1-month follow-up after treatment' and 'posttreatment versus 1-month follow-up after treatment') were significantly greater in the experimental group. (Figure 8-C) Otherwise, there were no between-group differences in terms of the MBI, EQ-5D index and BDI. (Figure 8-D, E, F)

(A)


60
50
40
30
20
10
0
21.50
31.17
34.67
24.50
43.58
53.75
control
experimental
pre
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1mo F/U
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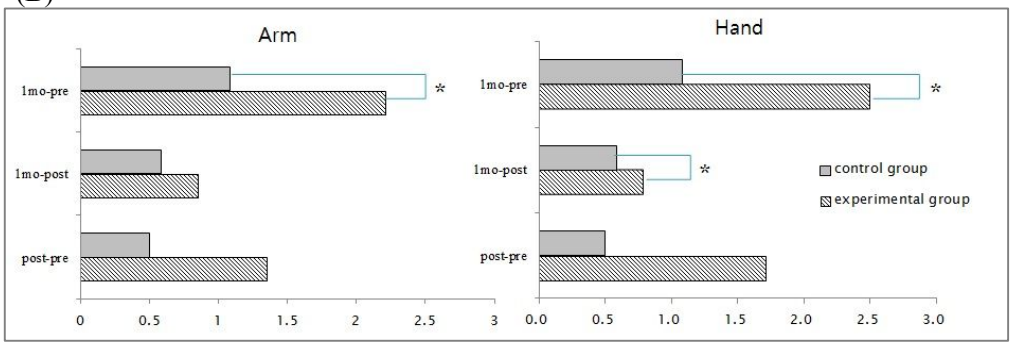
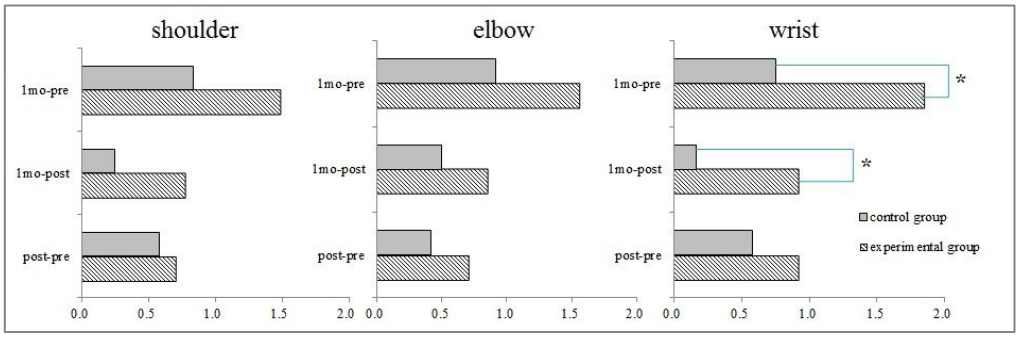
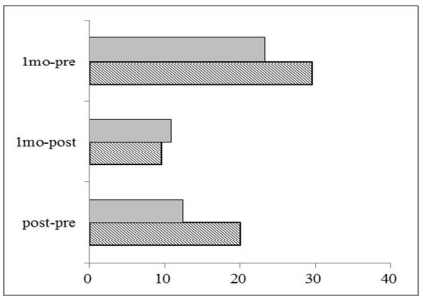
(B)


Arm
1mo-pre
1mo-post
post-pre
0
0.5
1
1.5
2
2.5
3
Hand
1mo-pre
1mo-post
post-pre
0.0
0.5
1.0
1.5
2.0
2.5
3.0
control group
experimental group

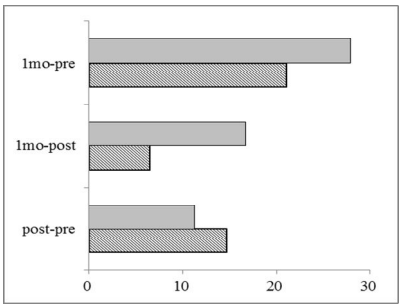
(C)


shoulder
elbow
wrist
1mo-pre
1mo-post
post-pre
0.0
0.5
1.0
1.5
2.0
control group
experimental group

(D)


1mo-pre
1mo-post
post-pre
0
10
20
30
40

(E)


1mo-pre
1mo-post
post-pre
0
10
20
30

(F)

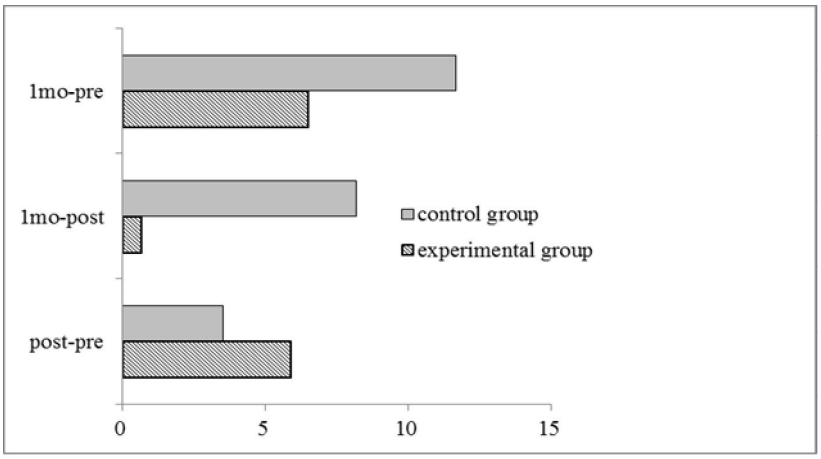


Figure 8. Changes in the outcome measures

(A) Change in the Fugl-Meyer Assessment of the Upper Extremity

(B) Change of in the Brunnstom stage (arm and hand)

(C) Change in muscle power measured by the manual muscle test (shoulder/ elbow/ wrist)

(D) Change in the modified Barthel index

(E) Change in the EQ-5D index

(F) Change in the Beck depression inventory

Mo: month, pre: before the rehabilitation program, post: after the rehabilitation program, F/U: follow-up

Q***uestionnaire***

A user satisfaction questionnaire was administered following treatment. The 5-point Likert rating was used to assess responses to the questions (higher values represented greater satisfaction with the treatment). Participants in the experimental group were also asked about the MoU-Rehab. User satisfaction in the experimental group was not inferior to that in the control group. Participants in the experimental group responded positively to all items. The mean scores on all items were above 4 on a 5-point scale. Additionally, they responded that they were willing to pay $22 ± 10 (range, $10–40) for game applications in the MoU-Rehab. (Table 10)

Table 10. Results of the user satisfaction survey administered after treatment was completed

Question	Experimental group (n=12)	Control group (n=12)
The upper extremity rehabilitation program provided sufficient treatment for me.	4.17 ± 0.72	4.00 ± 0.85
The upper extremity rehabilitation program provided on target services to you	4.42 ± 0.52	3.92 ± 1.00
In general, I am satisfied with the upper extremity rehabilitation program .	4.25 ± 0.75	3.92 ± 1.00
The upper extremity rehabilitation program helped me to better manage my health and medical needs.	4.33 ± 0.65	4.00 ± 0.74
The display of the program was adequate.	4.25 ± 0.62	
The program had good readability.	4.25 ± 0.62	
It was convenient to use the program.	4.08 ± 0.67	
How much money would you be willing to pay for this program? $ (range)	$22 ± 10 ($10-40)	

Discussion

We developed mobile non-immersive virtual reality upper extremity rehabilitation program using game applications. The present study evaluated the feasibility and clinical effectiveness of the MoU-Rehab. Our findings showed that the MoU-Rehab effectively promoted upper extremity recovery in patients with stroke. When comparing the MoU-Rehab to conventional therapy only, treatment using the MoU-Rehab showed greater improvement in the FMA-UE, B-stage and MMT. Comparable improvements were shown in the MBI, EQ-5D and BDI. In addition, patients in the experimental group completed the 2 weeks treatment using the MoU-Rehab without adverse effects and they were generally satisfied with the MoU-Rehab.

Even though numerous studies have attempted to use VR-based rehabilitation therapy for patients with stroke, a few large controlled studies have compared the benefits of conventional therapy to VR based therapy. Most studies that compared the two therapy methods allowed more rehabilitation time in the experimental group.[39] We cannot exclude the possibility of the effects of intensity and frequency of the rehabilitation per se.[51] Furthermore, many studies have focused on only a single aspect rather than on multiple aspects (eg. motor impairment, activities and social

participation/quality of life). Also, usually short-term effects were only reported. Unblinded assessments and biased patient selections (i.e., only patients with mild to moderate impairment were included) can create bias in favor of the VR based rehabilitation therapy.[52, 53] Therefore, we tried to design a randomized, controlled trial and match the treatment dose. Additionally, we attempted to evaluate multiple aspects by means of various outcome measures (e.g., motor impairment by the MMT, arm and hand function and activities by the FMA-UE, activity limitation by the MBI, participant restriction and quality of life by the EQ-5D, psychological aspects by the BDI and adverse events such as morning sickness and peripheral injury). We conducted 1-month follow-up evaluation after the treatment was completed to check the sustainability of the treatment's effectiveness. The assessors were blinded to group allocation. To collect more homogeneous patients, only ischemic stroke patients were enrolled.

Most game-based studies have used commercial off-the-shelf games.[43] However, those games were not specifically designed for patients with stroke. We developed a game program that targets patients with stroke. We made various kinds of game applications and selected some applications that could be used for these patients. We excluded game applications that could aggravate spasticity of the upper extremity (e.g., usually games that focused

on speed aggravated spasticity) and chose game applications that could induce desired movements and avoid synergistic movements.

We designed the mobile program with a smartphone and tablet PC. Since penetration of smartphones and tablet PCs are increasingly used in the general population, it is relatively easy to implement the treatment programs using these handheld mobile devices with low costs. Considering the lightweight and small size of these mobile devices, they are portable and easy to use regardless of one's location. Although we administered the MoU-Rehab in the therapy room to strictly match the treatment time between the two groups, this program can also be used in home settings. We expect that the MoU-Rehab would be a good candidate tool for telerehabilitation for upper extremity recovery in patients with stroke.

We speculated that the therapeutic effectiveness of the MoU-Rehab was equal or greater than that of conventional therapy because of the game's effects. Participating games may facilitate motor learning[54], while increasing interests in rehabilitation and promoting motivation. Moreover, auditory and visual feedback can facilitate patients' desire for interaction. These factors may increase the efficacy of rehabilitation therapy by achieving a high level of patient adherence to training and increasing engagement in therapy.

The findings of the present study suggest that this mobile game-based VR

upper extremity rehabilitation program can substitute some parts of conventional therapy that are delivered one-on-one by an occupational therapist. However, our study has a few limitations. The first limitation stemmed from the study's small sample size. Although we tried to randomly allocate patients to the two groups, we allocated patients by the admission period to keep patients blinded to their group allocations. In addition, the mean age of the two groups was not the same. Although we conducted a 1-month follow-up evaluation, more long-term follow up evaluations are necessary to confirm how long the treatment's effectiveness is maintained. Although we encouraged to use mobile upper extremity rehabilitation program for 30 minutes a day, we could not measure the real amount of engagement and break time during the therapy. In the present study, no kinematic data were available. Kinematic data such as linear and angular displacements, velocity, and acceleration can provide more specific information about movement components and strategies through space and time.

Conclusion

We propose a time-efficient, easy to implement, and clinically effective programs for the recovery of aphasia and upper extremity dysfunction in patients with stroke. We gained scientific evidence for efficacy and feasibility of home-based mobile rehabilitation programs as a way of u-Health service. More programs to supplement the shortcomings of the present study can be applied to stroke rehabilitation. Patients and therapists will collaborate remotely through these e-health rehabilitation programs while reducing economic and social costs.

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초 록

뇌졸중 환자의 실어증과 상지 기능 회복을 위한 모바일 프로그램의 개발 및 유효성 검증

뇌졸중 환자의 재활치료는 반복적이고, 목표지향적이며, 충분한 치료의 강도와 시간을 확보하는 것을 원칙으로 하고 있다. 이에 본 연구에서는 뇌졸중 후 실어증 및 상지 기능 장애가 있는 환자를 대상으로 최근 각광 받고 있는 u-헬스 서비스를 모바일 기기를 이용하여 제공하는 프로그램을 개발하고자 하였다.

실험 1. 뇌졸중 후 실어증을 위한 모바일 프로그램

1) 뇌졸중 환자의 실어증을 선별하는 원격 선별도구

모바일 기기를 이용하여 뇌졸중 환자의 실어증을 선별하는 검사를 개발하였다. 실어증 환자 30명, 비실어증 환자 30명을 대상으로 검사를 시행하여 유효성, 신뢰도, 민감도, 특이도, 진단적 정확성을 평가하였다. 모바일 실어증 선별검사도구의 검사 결과는 한국판 웨스턴 실어증 검사 결과와 고식적인 한국판 프렌차이 실어증 선별검사도구의 검사 결과와 높은 일치도를 보였다. 또한, 높은 검사자간 신뢰도와 민감도, 특이도, 진단적 정확성을 보였다. 이에 모바일 실어증 선별 검사도구는 뇌졸중 환자의 실어증을

선별하는데 유효하고 신뢰성 있는 도구임을 확인하였다.

2) 뇌졸중 후 만성 실어증 치료를 위한 원격 언어치료 프로그램

원격 언어치료 프로그램을 만들어 총 8명의 뇌졸중 후 만성 실어증 환자에게 4주간의 치료를 제공하였다. 치료 후 한국판 웨스턴 실어증 검사 결과가 유의하게 호전되었으며 그 호전 정도는 1달 뒤 재평가 시에도 유지되었다. 호전된 정도는 환자의 연령과 실어증의 중증도와는 무관하였으며, 환자가 치료 프로그램을 이용한 총 시간과 강한 상관 관계를 보였다. 치료프로그램에 대한 설문조사에서 높은 만족도로 응답하였다. 원격 언어치료 프로그램은 뇌졸중 후 만성 실어증 치료에 가능성있고 효과적인 치료임을 확인하였다.

실험 2. 뇌졸중 후 상지 기능 회복을 위한 모바일 프로그램

뇌졸중 후 상지기능 회복을 위하여 스마트폰과 태블릿 PC를 이용한 가상현실 기반의 게임 프로그램을 개발하였다. 허혈성 뇌졸중 환자 24명을 각각 12명씩 실험군 및 대조군에 무작위 배정하였다. 대조군의 경우 고식적인 재활치료 60분을, 실험군의 경우 고식적인 재활치료 30분 및 모바일 상지기능 재활치료 프로그램을 30분을 제공하였다. 2주간의 치료 후 두 군 모두에서 Fugl-Meyer 상지 평가 척도, Brunnstrom의 회복단계, 근력, 수정바델지수, EQ-5D 삶의 질 평가, 우울증 척도의 유의한

호전을 보였다. 특히 Fugl-Meyer 상지 평가 척도, Brunnstrom의 회복단계, 근력은 실험군이 대조군보다 유의하게 더 큰 호전을 보였고, 나머지 평가에서는 두 군간의 차이는 없었다. 또한 치료프로그램에 대한 설문조사에서 높은 만족도로 응답하였다. 이에 모바일 상지기능 재활치료 프로그램은 허혈성 뇌졸중 후 상지기능 회복을 촉진하는데 가능성 있고 효과적인 치료 방법임을 확인하였다.

본 연구를 통해 뇌졸중 환자의 실어증 및 상지 기능 장애 회복을 위한 모바일 프로그램을 개발하였고, 임상적 적용 가능성과 효과에 대해 검증하였다. 이에 u-헬스 서비스의 일환으로 모바일 프로그램을 사용하여 가정에서도 재활치료가 시행될 수 있음을 확인하였다. 또한, 추후 이번 연구의 단점을 보안한 다양한 프로그램을 개발하여 뇌졸중 재활치료에 폭넓게 적용할 수 있을 것으로 기대된다.

주요어: u-헬스, 모바일헬스, 뇌졸중, 재활치료, 실어증, 상지, 텔레헬스, 원격의료

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