Experimental Verification of Contents Usability for Upper Limbs Rehabilitation in Patients with Hemiplegia

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Abstract. Patients with hemiplegia with upper limb impairment have difficulties in performing coordinated bimanual movement of hands and activities of daily living (ADL) due to reduced performance in functional movements. This study developed a serious game for upper limb rehabilitation training using a balance handle specifically designed for patients with hemiplegia. Most current serious games designed for healthy people constitute difficulties for hemiplegia patients to use. For this reason, the simple game interface adapted to accommodate patient disabilities and the content tailored to the needs of these patients are warranted to provide gaming environments according to each patient's condition. Therefore, this study designed the tailored content that offers an environment appropriate for each patient by evaluating range of motion (inclination of a balance handle) of hemiplegia patients, movement speed and others. This game content is designed based on extension, flexion and movement assessment guidelines for the Fugl-Meyer Assessment (FMA), and measures muscle activities of triceps, biceps and deltoid muscles which demonstrate changes in upper limb motor function while performing the content. The experiment results revealed that triceps, biceps and deltoid muscles were activated. This content is expected to be utilized for rehabilitation purposes in hemiplegia patients with upper limb impairment.

Keywords: Hemiplegia · Limbs rehabilitation · Serious game · EMG · FMA

1 Introduction

Hemiplegia refers to the status of hypotonia in face or upper or lower limb on the affected side of brain damage. It causes muscle regulatory ability impairment, muscle tone weakening, etc. to develop paralysis or synergy symptom where one cannot move one single muscle but a group of muscles simultaneously [1]. Most of the hemiplegia patients have upper limb functional disorder from minor to severe degree and its accompanied functional movement weakening that undermines not only the coordinate movement of both hands but also activities of daily living [2]. In general, hemiplegic patients can enjoy high efficiency of rehabilitation treatment if received within 7 days of disease occurrence before muscular rigidity. Particularly, to help reduce the aftereffect from

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cerebral nerve rearrangement due to neuro-plasticity or restore exercise function, rehabilitation treatment is necessary in the initial stage [3]. To facilitate neuro-plasticity, patients' active participation is required in addition to repeated exercise. Rehabilitation treatment methods known to many include Fugl-Meyer Assessment (FMA) and Motor Assessment Scale (MAS). Most of them rely on therapists' supervision to make patients follow repeated moves for functional damage minimization and damaged brain nerve recovery [4]. Other effective rehabilitation treatment research methods include Constraint Induced Movement Therapy, Mirror Therapy, Bilateral Upper Extremity Training, and Rehabilitation Robotics. These are to improve the ability to control the upper limb muscles on the affected side of hemiplegic patients for enhanced exercise function on the affected side [5–8]. However, even the patients with the same impairment can still show mutually different results depending upon the subjective evaluation method of therapists. Therefore, an objective evaluation method is necessary, which can represent qualitative results. In addition, rehabilitation training requires continued participation, and, for this characteristic, it is also demanded to explore how to stimulate patients' interest for their active participation [9]. Against this backdrop, research has been actively made on quantitatively measuring or analyzing physical movements during rehabilitation exercise by attaching miniaturized inertial sensor, electromyogram sensor, etc. to body; and on functional games capable of stimulating activeness and interest [10, 11]. Most of the known functional games are generally made for normal people, posing plenty of difficulties for hemiplegic patients to use. But they are more interesting than conventional rehabilitation training methods by utilizing a lot of devices capable of somatesthesia or movement, reinforcing patients' will to participate. In this sense, when producing a functional game for hemiplegic patients, it is necessary to develop a simple interface and tailored contents to implement according to each patient's status. In this present study, for reinforced upper-limb muscular function and improved range of motion of hemiplegic patients, an acceleration sensor-based bilateral rehabilitation exercise device (balance handle) was employed as the functional game interface [12]. The triceps, biceps, and deltoids activation status of the developed functional game was measured to see if it could be utilized for hemiplegic patients as a rehabilitation content. Moreover, tailored contents were produced, which measure the range of motor (balance handle inclination) and movement velocity according to patients' hemiplegia degree, then, configure an appropriate contents environment for each patient.

2 Materials and Methods

2.1 Balance Handle and Electromyogram Measurement Location

Balance Handle employed in this study is shown in Fig. 1(a). For hemiplegic patients with restricted movement due to weakened upper-limb muscle, the device was designed to support their upper limbs. Balance Handle consists of 3-axis acceleration sensor, MCU, Bluetooth module, etc. inside. For the acceleration sensor, Analog Device's ADXL335 model was employed to acquire the inclination to the x, y, and z directions. In MCU (ATmega16), the acquired 3-axis data voltage values of acceleration sensor were sampled with 100 Hz. Not to disturb Balance Handle operation movement, Bluetooth module (Firmtech's FB155BC) was employed and, by doing so, the inclination data transmitted to PC were utilized to control the developed contents. Among the upper-limb rehabilitation movement assessment methods checking the degree of recovery of upper-limb motor function of hemiplegic patients, the developed contents based on FMA flexion-extension motion to operate Balance Handle. Balance Handle basically moves to the top, bottom, right and left up to the maximum inclination of 22° to the top; 28°, bottom; 16°, left and right. To check the muscle activation of triceps, biceps and deltoids according to Balance Handle move, EMG electrodes were attached at certain intervals from about 2 cm away along the muscular grain from upper-limb muscle center as in Fig. 2 ①, ②, and ③. A reference electrode was attached on the outer side of elbow of ④ without any change in muscular activation.

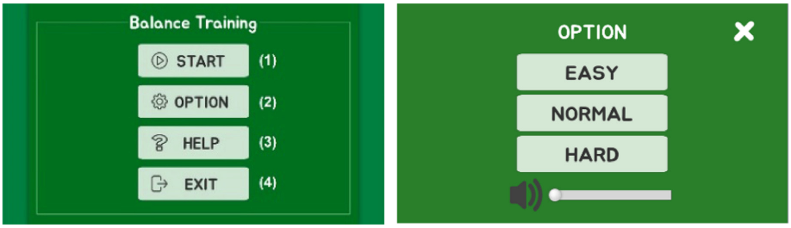
(a) (b)

Fig. 1. Balance handle and EMG sensor location and a balance handle

2.2 Production of Tailored Upper-Limb Rehabilitation Training Contents

The developed content is to gain a high score by avoiding obstacles or vehicles appearing while driving a car on a highway; earning events (refuel coin); and refueling the car to run a longer time.

Figure 2(a) shows the game start page. (1) is game start button. (2) allows to adjust game difficulty levels or sound volume as in Fig. 2(b). Difficulty levels were adjusted to change the frequency of obstacles (vehicles), vehicle types, fuel consumption, etc. At the difficulty level, Easy, a single vehicle appears less frequently for all people to get used to the game easily. As the difficulty level moves from Normal to Hard, cars running



(a) Game start page (b) Setup page

Fig. 2. Game user interface

on the highway appear irregularly in different types and speed. User car consumes fuel faster so, to game for a longer time, users have to earn a lot of events (refuel coin) appearing on the screen. The help button in (3) explains simple operation method and game details.

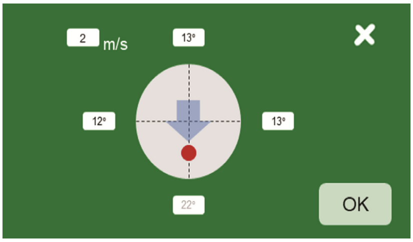
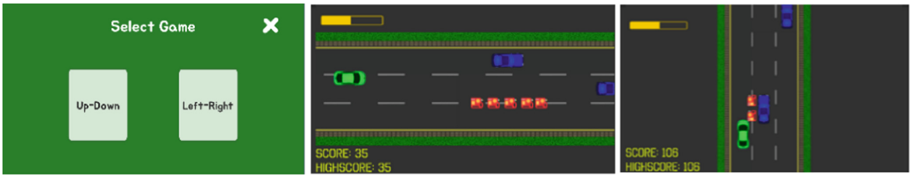


Fig. 3. Inclination and movement speed of a balance handle by user

Figure 3 shows the screen to measure the max up, down, left and right-directional inclinations and movement velocity of Balance Handle as each patient has different degrees of range of motion according to their disease status. Based on the information obtained here, the game environment is tailored to each user. At the basic difficulty level set up previously, the relative speed of car and obstacles, inclination, obstacle frequency, initial fuel amount, etc. are additionally set up in line with user characteristics so that mild through severe case patients can enjoy the game.



(a) Game model selection page (b) Flexion-extension training (c) pronation-supination training

Fig. 4. Game execution page (Color figure online)

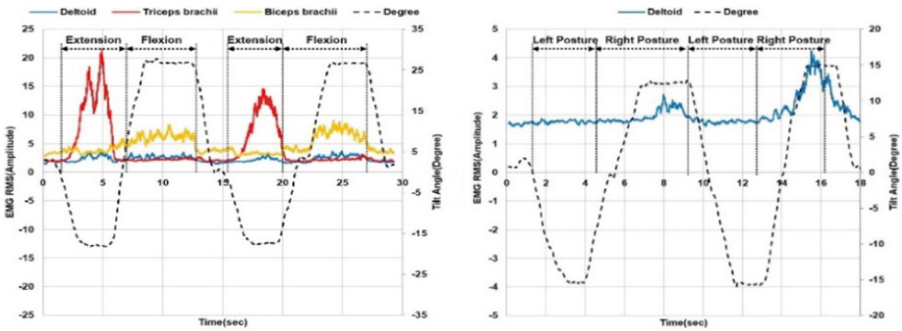
Figure 4(a) is the page to select the up-down exercise mode for flexion-extension training as patients wish in their rehabilitation training and the left-right exercise mode for below-elbow pronation and supination.

In Fig. 4(b), as a user moves Balance Handle to the top and bottom (flexion-extension move), the green-colored car moves up and down in the game. The yellow fuel gauge on the upper left side of the screen shows remaining vehicle fuel amount, which decreases slightly as while gaming. On the lower left part of the page, a user's present score is displayed in SCORE and the highest score of users so far, in HIGHSCORE, to stimulate their competition and encourage voluntary participation. SCORE increases with game hours and drops if collided with an obstacle. Since the fuel gauge gradually decreases while gaming, users have to gain events (red-colored refuel coins) to continue their game and score more. Figure 4(c) shows the left-right mode (pronation and supination training) which is progressed identically to the top-bottom mode.

2.3 Experiment Method and Results

In the experiment of this study, 7 normal men aged between 24 and 27 without any hemiplegic history were investigated. As they were gaming, change in their triceps, biceps and deltoid EMG signals was measured. The subjects were sufficiently told about the experiment method. To avoid any difficulty in placing their arms on the Balance Handle device, a height-adjustable chair was utilized to ensure they were in the most comfortable position in the experiment. Before game start, the subjects' Balance Handle range of motion and inclination velocity were measured but, since they had no big difference, it did not have any special effect on game environment setup.

Figure 5 shows the muscular activation measurement results in the up-down and left-right modes of the car game developed in this study. As shown in Fig. 5(a), in the extension move, the triceps show the largest muscular activation; and, in the flexion, the biceps. Since the left-right mode experiment of this study collected data when the EMG sensor was attached only to the left-side upper limb, the muscle activation of left-arm deltoid was found increase when the subjects took a motion to the right. Such a result is consistent with that of previous study measuring muscle activation in Balance Handle up/down, left/right exercise [12]. In other words, the car game developed in this study makes users follow up/down, left/right exercise using Balance Handle to induce change in the activation of triceps, deltoids and biceps, by which the muscular function recovery in patients who need upper-limb rehabilitation is evaluated.



(a) Up-down mode (b) Left-right mode

Fig. 5. Results of muscle activation measurement

3 Conclusions

In this study, a functional game (Serious Game) was developed for rehabilitation training using Balance Handle developed for the purpose of supporting hemiplegic patients' upper-limb muscle function reinforcement and range of joint motion recovery. The functional game was basically for upper-limb motor rehabilitation while allowing visual, auditory physio-feedback to increase patients' motivation and voluntary participation in the training process. Since people with restricted movement such as hemiplegic patients have difference in the range of joint motion and movement velocity according to their disease status; their range of joint motion (Balance Handle inclination), and movement velocity were measured to configure an appropriate content environment for each patient. In this manner, the game sought to include hemiplegic patients to perform the contents for rehabilitation training without special difficulty. To check the effect of the developed contents, patients' triceps, deltoid and biceps activation status was measured, which are relied upon to evaluate patients' muscular function recovery, while they perform the rehabilitation contents structured based on the evaluation items of FMA (Fugl-Meyer Assessment) extension and flexion exercise. As a result of the experiment, in the up-down exercise, biceps and triceps were found activated; and, in the left-right exercise, deltoid activation was found. The findings are similar to triceps, biceps and deltoid muscular activation in hemiplegic patients' conventional upper-limb rehabilitation training moves using other devices [13, 14]. That is, while performing the functional game developed in this study, it can be utilized as a content of rehabilitation training for hemiplegic patients with upper-limb functional impairment.

Since this study experimented normal subjects, change in pre/post-training range of motion and movement velocity could not be identified. These will need to be investigated in an experiment in cooperation with a hospital capable of performing a clinical test on actual patients. Moreover, through game type diversification and difficulty level sub-fragmentation, tailored functional games should be researched, which are capable of adjusting difficulty levels or recommending contents to follow according to each patient's present status.

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