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# MusicGlove: Motivating and Quantifying Hand Movement Rehabilitation by using Functional Grips to Play Music

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*Abstract*— **People with stroke typically must perform much of their hand exercise at home without professional assistance as soon as two weeks after the stroke. Without feedback and encouragement, individuals often lose motivation to practice using the affected hand, and this disuse contributes to further declines in hand function. We developed the MusicGlove as a way to facilitate and motivate at home practice of hand movement. This low-cost device uses music as an interactive and motivating medium to guide hand exercise and to quantitatively assess hand movement recovery. It requires the user to practice functional movements, including pincer grip, key-pinch grip, and finger-thumb opposition, by using those movements to play different musical notes, played along to songs displayed by an interactive computer game. We report here the design of the glove and the results of a single-session experiment with 10 participants with chronic stroke. We found that the glove is well suited for use by people with an impairment level quantified by a Box and Blocks score of at least around 7; that the glove can be used to obtain a measure of hand dexterity (% of notes hit) that correlates strongly with the Box and Blocks score; and that the incorporation of music into training significantly improved both objective measures of hand motor performance and self-ratings of motivation for training in the single session.**

## I. Introduction

Stroke remains the leading cause of chronic adult disability in Western countries with over four million survivors currently living in the United States [1]. Following the onset of stroke, up to 85% of patients exhibit initial hand motor impairment for the first few weeks, and up to 75% six months post initial assessment [2]-[4]. Intensive movement training can reduce motor impairment after stroke [5]. Unfortunately, the length of stay at inpatient rehabilitation facilities is now often limited to two weeks and outpatient physical therapy to two times a week thereafter [6]. Patients are therefore expected to perform intensive therapy at home with little direct supervision during the time window when the brain is most plastic [7]. Current home hand therapy typically consists of patients following through written sheets of exercises [8]. Without feedback and a motivating context for exercise, people often cease exercising the hand.

Repetitive massed practice of movements and the intensity of movement are two of the most important factors for regaining motor function [9]-[11]. Music is a promising avenue for therapy because of its highly repetitive and motivating nature [9], [12]. Moreover, music therapy has been hypothesized to induce better cortical connectivity and improve motor cortex activation [9], [13]. Recognizing these potential benefits, several forms of music based therapy have emerged which focus on movement repetition and auditory feedback about movement precision [9], [12], [14].

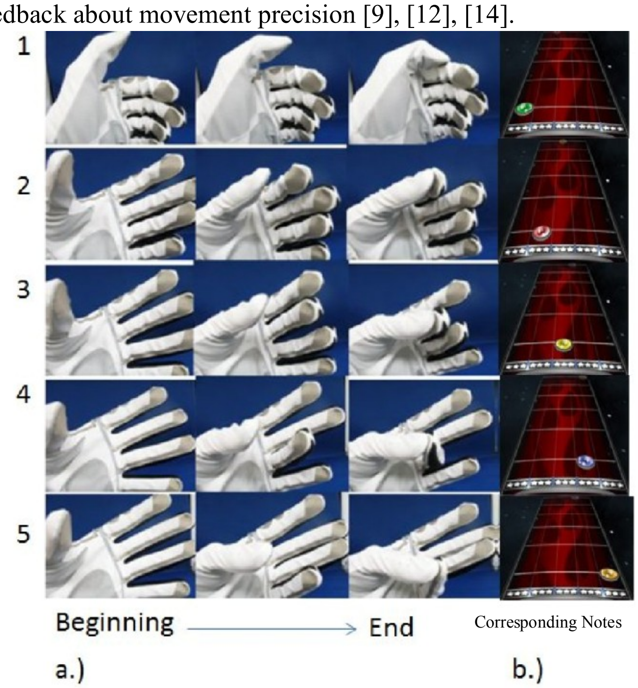


Fig. 1 a.) The five hand movements trained using MusicGlove, shown in three frames each progressing from beginning to end of the movement. When the user touches the thumb lead to one of the other 5 electrical leads, a distinct event is sent to the computer through the USB port b.) The MusicGlove interfaces with a computer game called FOF. In the game, colored notes scroll down the screen on five distinct frets. When the notes reach the bottom of the screen, the user must touch one of the five respective leads on the glove with their thumb within a 300 ms time frame. Hitting the note increases the volume of the music. Correct notes are logged and displayed in a summary at the end of the level providing a quantitative assessment of hand function.

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Technology for music-based therapy of hand movement is also emerging. For example, one study used a customized electronic keyboard and drum pad designed to train both fine as well as gross hand movement [9]. In another study, participants used a robotic and virtual system to play a simulated piano with the intent of training hand function [16]. Although these devices promote recovery of hand function, they do not specifically train the hand movements used in activities of daily living (ADLs).

Our working hypothesis is that a musical training device that focuses on training functional hand movements will be more effective than a device that does not train such movements, due to the principle of specificity of motor training [17]. In other words, we hypothesize that people will improve function more if they practice the actual movements required for function.

We therefore developed MusicGlove as a low cost device (< $100) for home hand rehabilitation. MusicGlove uses music as an interactive and motivating medium for therapy and to gain a quantitative assessment of the user's progress. In addition, we designed MusicGlove to require performance of functional gripping movements to play musical notes; these movements include pincer grip, key-pinch grip, and finger-thumb opposition.

The device presented here is similar to another glove based hand therapy device known as the HandTutor [18]. However, based on the published report of its use, the HandTutor does not appear to be focused on using musical training for therapy. The HandTutor also focuses on finger range of motion exercises rather than on having the user complete pinch and grasp functions that are used in many ADLs.

This paper describes the design of the MusicGlove and the results of initial single-session testing with the device. In this testing, we sought to understand what level of impairment the device was suited to treat; whether the quantitative measurements from the glove correlated with clinical scales of hand function; and whether people found the musical context for therapy motivating.

## II. Methods

### A. Device Design

MusicGlove is composed of a glove designed to train functional hand movements through interactive music-based computer games.

#### 1) Glove

The glove contains six electrical leads located on all five fingertips and one on the proximal interphalangeal joint on the lateral aspect of the index finger. When the lead on the thumb touches any of the other five leads, an electrical connection is closed which is then registered by the computer as an event. The placement of the electrical leads forces the patient to engage in pinch and grasp motions associated with activities of daily living (ADLs), as well as thumb-finger opposition [19].

We have initially designed MusicGlove to be used to play music on a pentatonic scale, common in Rock and Blues music. Fig. 1a shows the five movements that correspond to the five musical notes. It is possible to incorporate more notes by combining finger movements or placing more leads, or by using sensing of hand orientation to influence note selection.

#### 2) USB-Controller

A USB-controller was built to interface the glove with a computer. A PIC18F14K50 microcontroller sends a unique output to the computer corresponding to each of the five digital inputs it receives.

### B. Software

The MusicGlove is interfaced with a modified version of Frets on Fire (FOF)—an open source computer game similar to Guitar Hero©. During this game, five distinct notes scroll from the top to bottom of the screen (Fig 1b). When a note touches the stars at the bottom of the screen, the user has a 300ms window to touch the thumb to the specific electrical lead associated with that note. Each note is synchronized with a song in order to create the perception of playing the song with the glove. The goal of the game is to correctly hit as many notes as possible by the end of the level.

In order to use FOF for hand rehabilitation, several modifications were made to the source code. First, the graphical user interface and song selection were reconfigured towards people over age 50, as this is the predominant age range for people with stroke. When developing the songs, the difficulty level of each song was also configured to match the skill level of individuals with different levels of hand impairment. Moreover, the computer game was modified to enable both user and therapist to gain a quantitative assessment of motor function at the end of each song. The MusicGlove quantitative assessment shows: the number of correct notes hit on each fret, total number of correct notes hit, and an average of how close in time the individual was to hitting the note at the correct time. Specifically, the timing term is calculated as:

$$\bar{X} = 1/n \sum_{i=1}^{n} X_i \qquad (1)$$

Where X = deviation in time of a correctly hit note (has to be within 300ms window to be considered correct), and n = the total number of correctly hit notes in a level.

### C. Participants

A total of 10 participants who had experienced a stroke within the past three years were enrolled in the study (mean duration past stroke = 41.8 months +/- 15.6 SD). All participants had severe to moderate hand impairment as a result of stroke (Box & Block Test 0-46; 60 = normal).

Participants provided informed consent according to the protocol approved by the U.C. Irvine Institutional Review Board.

### D. Procedure

Motor function was first assessed using the Box & Blocks test by a trained physical therapist [15]. This assessment, which requires the testee to grab, move over a barrier, and drop as many blocks as possible in a one minute period, is widely used in motor rehabilitation of the upper extremity, and has good reliability and validity. Next, each participant donned the glove and was instructed how to generate an event by correctly touching the thumb to one of the five leads. The participant then played a tutorial in FOF that explained how to correctly match each of the five events with the five notes on the screen. The participants then began the training phase. Half of the participants played a level associated with the song *Can't Help Falling in Love* three times with music and then three times without music (i.e. with the speaker turned off, but still with the graphical interface showing the desired notes). The other group played *Can't Help Falling in Love* three times without music followed by three times with music. The trial was 2 minutes 59 seconds in duration and contained a total of 82 notes, of which 28, 27, 27, 0, 0 of the notes were located on frets 1-5 respectfully. Participants were given a maximum of one minute in between trials. At the end of each trial, the MusicGlove quantitative assessment was recorded. After all six trials were completed, the participants were asked to fill a questionnaire about their experience with the device.

## III. RESULTS

### A. Comparison of MusicGlove quantitative assessment with an established clinical measure of hand function

Fig. 2 Shows the average percent of total notes hit versus the Box and Blocks score of each of the 10 participants in the study. There was a significant linear relationship between MusicGlove performance in FOF and Box and Block score ($\beta = 0.51$, $t(9) = 10.76$, $p<0.001$, $r^2 = 0.79$). Note that two of the 10 participants enrolled in the study could not participate in the training phase due to an inability to close the contacts between the thumb and other leads. These participants had Box and Blocks scores of 0 and 2. A third participant with a Box and Blocks score of 7 was able to participate in the training phase.

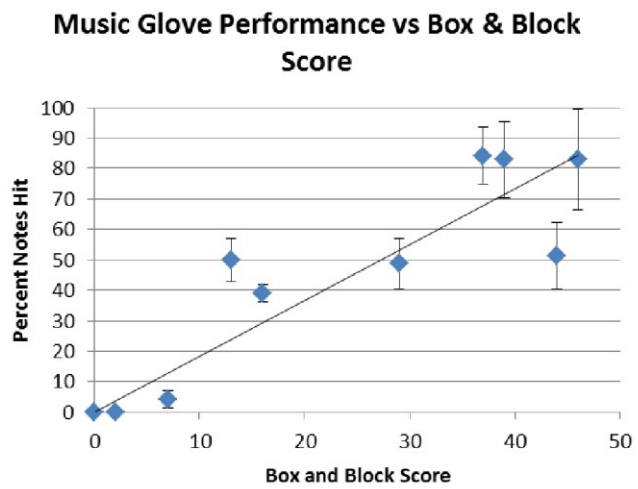


Fig. 2. Average percent of total notes hit significantly predicts box and block score, $\beta = 0.51$, $t(9) = 10.76$, $p<0.001$, $r^2 = 0.79$. Error bars represent one standard deviation.

### B. Role of music in motor performance and motivation

Participants attempted to perform the gripping movements with and without the musical feedback; in both cases they received graphical feedback from the computer screen about the desired notes and success in hitting those desired notes with the correct timing. Participants scored on average 10% higher, in terms of percentage of musical notes successfully played, when receiving music feedback (paired t-test, $t(7) = 2.38$, $p = 0.048$).

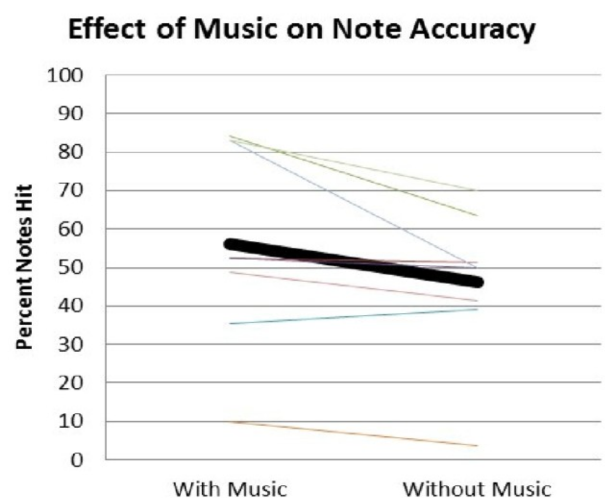


Fig. 3. Participants on average performed 10% better in FOF level with music than without (paired t-test, $t(7) = 2.38$, $p = 0.048$). The thin lines represent the outcome of each participant. The thick line represents the average of these results.

We also evaluated the average note timing term ($\bar{X}$) with and without music. As seen in fig. 4, participants on average did not show any significant difference in timing when playing the levels with and without music (paired t-test, $t(7) = 0.43$, $p = 0.435$).

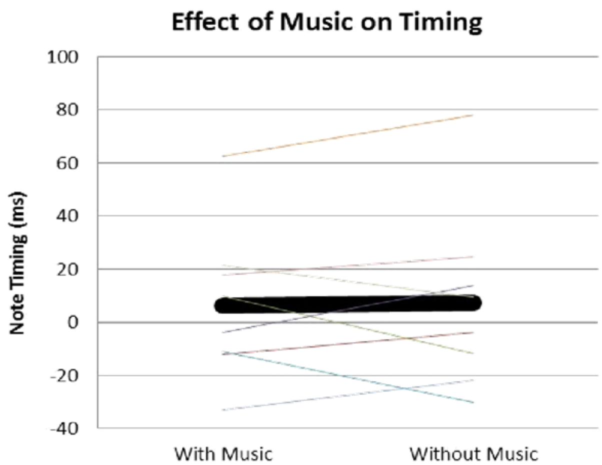


Fig. 4. Comparison of average note timing with and without music. Participants did not show a significant difference in the timing of hit note with and without music (paired t-test, $t(7) = 0.43$, $p = 0.435$). The thin lines represent the outcome of each participant. The thick line represents the average of these results.

Fig. 5 shows the adaptation to playing FOF over the six trials. On average, participants improved in total amount of hit notes by 19.9% (SD = 18.5) from the first trial to the last. A paired t-test revealed a highly significant improvement in percent of total notes hit from the first trial to last, $t(7) = 3.94$, $p<0.001$.

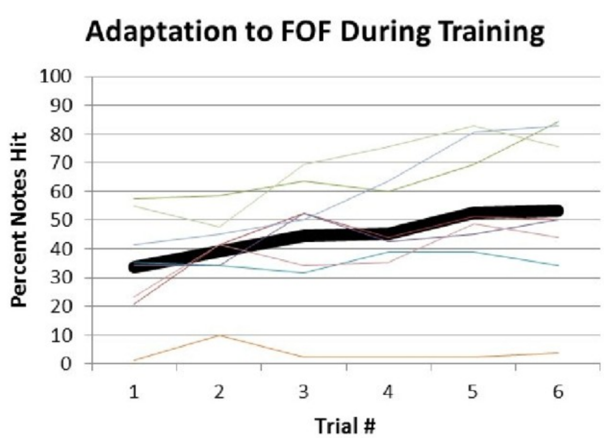


Fig. 5. Percent total notes hit for each trial increases on average over the length of the training regimen. The thin lines represent the outcome of each participant. The thick line represents the average of these results.

After the training session, we asked participants to complete a survey evaluating their experience (fig. 6). They found the training motivating, challenging, and desirable for home use. The participants found training with music to be significantly more motivating than training without music (paired t-test, $t(7) = 5.6$, $p<0.001$).

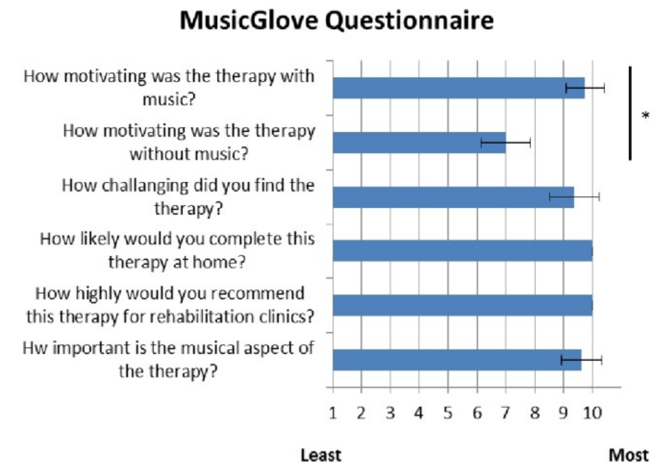


Fig. 6. MusicGlove questionnaire shows that individuals approve of the therapy, and find it motivating. Participants found therapy with music to be more motivating than therapy without music (paired t-test, $t(7) = 5.6$, $p<0.001$). Error bars represent one standard deviation.

## IV. Discussion

We developed a low-cost device that senses when people complete functional grips, including pincer grip, key pinch, and thumb-finger opposition. We interfaced the glove to a music game that requires the player to try to play notes along to songs using the functional grips. We tested the glove in a single session test with 10 people with a chronic stroke. The findings from this test and their significance are as follows.

First, we found that the glove is suitable for use by people with an impairment level quantified by a Box and Blocks score of approximately 7 or above. This means that the glove is suitable for people who have a moderate to low level of hand impairment. Note that all individuals who were able to use the glove to play music were able to don it without assistance; thus the glove is suitable for home-use by the population who can engage in its training paradigm. We are currently working on a robotic version of the glove that could assist people with a more severe level of hand impairment in using the same musical paradigm to exercise [20].

Second, we found that the glove can be used to obtain a measure of hand dexterity (% of notes hit) that correlates strongly with the Box and Blocks score. Since Box and Block score is an established indicator of hand motor function, this strong correlation indicates that MusicGlove can provide an objective measure of hand function. Moreover, this correlation suggests that improvement in MusicGlove performance will in turn lead to improved hand function.

Third, the use of music for training significantly improved both objective measures of hand motor performance and self-ratings of motivation for training. This finding suggests that patients will be both more engaged in the task during training and will be motivated to perform the therapy for long durations. Note that music improved the ability to hit the right note with the right grip, but did not improve timing. This result is contrary to previous findings [7]. A larger sample size is needed in order to validate this finding.

In conclusion, the MusicGlove was shown to be a motivating device for repetitive training of functional hand grips. Moreover, music was found to significantly increase the performance and motivation of the participants. Longitudinal clinical trials will be implemented to test whether training with the MusicGlove improves hand function after stroke.

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