Can Specialised Electronic Musical Instruments Aid Stroke Rehabilitation?

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Abstract
Stroke patients often have limited access to rehabilitation after discharge from hospital leaving them to self-regulate their recovery [1]. Previous research has indicated that several musical approaches can be used effectively in stroke rehabilitation [2][3][4]. Stroke patients (n = 43), between 6 months and 19 years post-stroke, took part in specially created workshops playing music, both in groups and individually, using a number of digital musical interfaces. Feedback forms were completed by all participants, which helped to develop the prototypes and gain insights into the potential benefits of music making for rehabilitation. 93% of participants stated they thought that the music workshops were potentially beneficial for their rehabilitation. The research project contributes to the field of HCI by exploring the role of computer based systems in stroke rehabilitation.

Author Keywords
Stroke Rehabilitation; Musical Interfaces; Pressure Sensor; Auditory Feedback

ACM Classification Keywords
J.3. Health; H.5.2. Prototyping; User-centered design

Introduction
Stroke is a leading cause of adult disability disproportionately affecting people from poorer backgrounds[5]. Physiotherapy (PT) and occupational therapy (OT) are the two standard disciplines involved in stroke survivors rehabilitation. The former usually focuses on motor disorders, while OT covers a wider set of needs in psychological and motor disorders [6]. Rehabilitation is a key part of patients’ recovery and has been shown to be effective, though it has proven hard to find out how much each intervention improves beyond patients’ natural recovery [7].

Stroke patients typically receive only limited rehabilitation after leaving hospital with many left to self-regulate their recovery [1]. Lack of motivation to perform physical exercises, coupled with a typically sedentary post-stroke lifestyle increases the risk of a secondary stroke [8].

Music Therapy (MT) can be incorporated into stroke rehabilitation in a variety of situations and many
techniques can be tailored to the physical goals and musical preferences of individual stroke survivors [3]. A 2007 study [4] undertook 15 sessions of MT over three weeks. Patients in the active music-making group demonstrated significant improvement in speed, precision, smoothness of movements and motor control during everyday activities, compared to control patients.

A recent journal promoted the use of neurological music therapy (NMT) for stroke rehabilitation by suggesting that it can be used to benefit patients’ neural and behavioural functions with translations to non-musical therapeutic outcomes [9]. Another study highlighted the way repetitive movements and auditory feedback during NMT (known as auditory sensorimotor coupling) can potentially be effective for stroke rehabilitation [10].

Electronic musical systems have been used in rehabilitation such as the Soundbeam (a system that allows for musical interaction via a MIDI hardware setup) [11]. The Soundbeam can be useful where patients have very limited movement as it does not require any pressure to activate. Apollo Ensemble is another system that allows for many different input and output scenarios, one of which is the Dual, a wireless squeezable trigger [12].

<table>
<thead>
<tr>
<th>MW</th>
<th>SP</th>
<th>ST</th>
<th>Duration</th>
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<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>4</td>
<td>2 hours</td>
</tr>
<tr>
<td>2</td>
<td>9</td>
<td>5</td>
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<td>3</td>
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<td>4</td>
<td>9</td>
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<td>2 hours</td>
</tr>
<tr>
<td>5</td>
<td>13</td>
<td>4</td>
<td>2 hours</td>
</tr>
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Table 1: Showing the five musical workshops (MW) with number of post-stroke participants (SP), staff (ST) and duration. The duration was set by the workshop leader and during a 2 hour session there was a break of 20 minutes in the middle.

The main focus of the research was to explore the interaction between patients and computers via specialised electronic musical devices. The project aimed to ascertain whether patients would be more motivated to perform repetitive upper limb movements by interacting with computer based rehabilitation aids. In addition a question of whether the devices would encourage patients to self-manage their rehabilitation were considered. Furthermore patients’ preferences for music making in group or individual settings were taken into account.

**Method**

**Participants**

The participants (n = 43) consisted of opportunity samples from five different community stroke groups aged 35 or above. Due to restricted access to their records, specific age and medical data were not available. However stroke group leaders stated patients ranged from 6 months up to 19 years post-stroke with a range of abilities common in long-term patients (aphasia, limited upper limb movement and the requirement of wheel chairs was common). The participants ranged from no musical playing experience to ex-professional musicians with a wide range of physical abilities. None of the participants had undertaken MT before.

**Procedure**

The project had three key stages. Firstly there was a scoping phase that involved meeting stroke patients (n=7) from a community group to discuss the possible role that music could play in their rehabilitation. The consultations fed directly into the design and implementation of two musical prototypes. All the patients indicated unanimous interest in trying a wide range of music based interventions linked to standard stroke rehabilitation exercises of the upper limb. Once the first generation of prototypes were prepared the first of five specially constructed musical workshops was completed with five post-stroke participants and four staff members lasting two hours. Over a period of six weeks four more musical workshops were undertaken in different community stroke group meetings with between 7 and 13 participants at each, lasting either one or two hours (see Table 1).

At the end of each workshop feedback forms were completed by all patients to gain qualitative data. Workshop reviews were also completed shortly after
each workshop summarizing any extra feedback from the participants, health experts, and support staff as well as listing the musical exercises undertaken. The participatory design highlighted technical issues with the prototypes between workshops utilizing an agile development methodology (a focus on iterations, and patient feedback).

**Prototypes**

The first proposed intervention was the **Musical Stress Ball** (a traditional stress ball with a pressure sensor inside Figure 1) inspired by comments made during the initial consultation. A number of stroke patients stated how they had used stress balls and therapeutty in their rehabilitation to help regain strength and flexibility in their hands, but had stopped using them due to a lack of motivation. The **Musical Stress Balls** (n=8) were trialled in all five workshops with all 43 participants playing them within their separate groups (see Table 1). Many patients during consultation explained how hard they found it to release cup handles (likely due to spasticity, a tightness in the muscles common post-stroke). These observations led to the rational behind a second proposed intervention called the **SoundBoard** (a felt covered board with 8 7x7cm pads to trigger musical events), designed with the aim of encouraging patients to lift objects, such as cups and other household items up and down on the surface to play music. The first version (SoundBoard) was trialled in the second and third workshops by 13 patients before expanding the prototype to a **SoundBoard2** (see Figure 2) in the final two workshops, were trials were made by 22 participants. The second design allowed the same melody or sequence of notes to be played in three different directions depicted with a simple numbering system as seen in Figure 2. This design was implemented after feedback from an OT stating that patients often need to perform arm reaching in multiple directions. Due to time constraints and fatigue some participants (n=5) were not able to play the **SoundBoard**. A third and final proposed intervention the **Electronic Chime Bar** was created inspired by a rehabilitation study of visual neglect [13]. However, due to a delay in completion this single prototype was not used until the final two music workshops and then was trialled by 20 of the participants.

To sonify the prototypes all three had a single pressure-sensitive conductive sheet of velostat (piezoresistive material) between two layers of conductive fabric. The velostat acted as a resistor between the fabric layers allowing for a range of pressure readings. All three prototypes used a similar approach allowing the user to activate musical samples or tones on a macbook pro by either squeezing and releasing (**Musical Stress Ball**) or pressing/hitting the surface (**SoundBoard** and **Electronic Chime Bars**) of the prototypes.

**Workshops**

As the stroke groups had many levels of cognitive and physical ability steps were taken were required by support staff and workshop leaders to help the patients reach instruments and make them comfortable. Each music workshop followed a similar format allowing all participants to engage in group music making activities. All participants and support staff who wanted to join in were given a single acoustic chime bar to play with a small beater using the affected limb wherever possible. All members were assigned to a small group of between two and three with each group assigned a bass note of a chord from a given song. The workshop leader conducted participants to play along to songs such as **Let It Be** by The Beatles (comprising four chords, thus four small groups formed, with each group playing either a D, G, B or A note). When participants had played through a song for around 10 minutes the **Musical Stress Balls** were introduced and assigned to the groups allowing them to play alongside the acoustic chime bars. There was either a single or dual mode to
select when playing the *Musical Stress Balls* being either single trigger (squeeze action) or double trigger (squeeze and release). The latter allowed for a more flowing sequence of notes to be attained with many participants playing musical scales such as C major, A minor and A blues.

All the electronic sounds where heard via a wireless speaker placed in the middle of the group so each participant could hear their own "instrument" sounding. Various sounds were heard when playing the *Musical Stress Balls* from Logic Pro libraries with the most common used being a *vibraphone* sounding very close in timbre to the acoustic chime bars. Participants were lead in other exercises using up to 8 *Musical Stress Balls* to play a full musical scale and simple melodies such as *Frere Jacques* (staff members make up numbers as required and during the larger workshops participants took turns so every patient participated).

Individual music making was undertaken for the last 20 minutes in workshops 2-5 by inviting participants to sit at a chair (or place their wheelchair) and play the *SoundBoard* or *SoundBoard2* located on a table top of standard height. They could either play scales and melodies by pressing the numbered squares (see Figure 2) or objects such as cups, bottles and cans were placed on the squares with the patients being required to lift them up and down in position to play sounds. The final workshop introduced the single *Electronic Chime Bar* which was incorporated from the start of the workshop replacing one of the acoustic chime bars; this gave the participants the choice of many musical sounds such as pianos, choirs and other samples to experiment with.

**Results**

All participants filled out feedback forms after completing the workshops. Each statement or question in the feedback form was designed to be minimally effortful for a stroke patient to answer with a simple ordinal scale of choices to answer. Some responses were left blank and these were noted in the chart data.

**Figure 3.** Four statements taken from participant feedback.

- **Q1:** I found todays session enjoyable
- **Q2:** I found today’s session potentially relevant for physical rehabilitation
- **Q3:** I am interested in informal music making in a group
- **Q4:** I am interested in informal music making one-to-one

Figure 3 shows that 98% of group members agreed they found the session interesting and 93% thought the session could be relevant for their physical rehabilitation. Statements (Q3 and Q4) showed that the majority of group members were more interested in group music making (n = 39) as opposed to individual (n = 32). Figure 4 shows that 98% of participants stated they enjoyed playing the *Musical Stress Balls*, while 87% who trialled the *SoundBoard* stated they enjoyed it and 82% of participants in the final two workshops enjoyed playing the *Electronic Chime Bar*. Additionally 5 of the participants showed interest in taking the prototypes home to practice and play music without any priming from workshop leaders or staff.

Feedback was also gained from a stroke specialist OT, speech therapist, stroke group leaders (n = 4), other
Figure 4. Participants responses to the following statements. Q5: I enjoyed playing the Acoustic Chime Bar Q6: I enjoyed playing the Electronic Stress Ball Q7: I enjoyed playing the SoundBoard Q8: I enjoyed playing the Electronic Chime Bar support staff and a psychologist. The OT indicated that making the prototypes adaptable to suit the specific abilities of patients was important and additionally that with more motivation from participants the difficulty of the task could be increased. The psychologist who attended the fourth workshop stated that she would like to recommend the activities for improving both mood and physical ability in her stroke patients as a useful “coping strategy”. The speech therapist stated that the use of stress balls was not actually recommended as widely as it used to be due to the contraction it encourages. However, all the health experts stated that some patients would still benefit from the squeezing movement and most would benefit from the release action as this supports extension in the fingers which is frequently encouraged. Table 2 displays combined feedback from the health experts on the potential uses of each prototype with specific reference to the physical movements they can help with during rehabilitation. The OT stated that movements should aim to translate into functional relevance in everyday life.

Discussion
The project explored the sonification of physical movements performed by stroke patients using three specialised musical devices. Feedback on the usability of the prototypes, from both stroke survivors and health professionals, suggested that the musical devices could play a motivational and relevant role in long-term stroke rehabilitation. However, further longitudinal studies are required to prove efficacy, as each participant only had a single musical workshop to play with the prototypes and none of them had previous experience of MT sessions as a comparison. Moreover the feedback statements (Figure 2 and Figure 3) are too broad to draw any firm conclusions from. Nevertheless the full qualitative range of feedback from patients and health experts did strongly suggest more research would be useful and could have much potential in rehabilitation settings.

The fact that patients wanted to take the devices home showed promise for self-management and continuation of protocols from clinic to home environment. The interfaces could potentially be used with a carer at home providing a meaningful, creative and social framework for rehabilitation. Yet because patients stated they were more interested in group music making as compared to individual suggests that a combination of individual and group rehabilitation should be investigated further.

Suggestions for future features to build into the prototypes were the following:

- Wireless capability: Presenting it in the form of a game-based app, so patients and clinicians can have a record of targets reached
- Electromyography (EMG): To help give detailed feedback of muscle movement to patients and

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<tr>
<th>MSB</th>
<th>Finger extension</th>
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<tr>
<td></td>
<td>Wrist extension</td>
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<tr>
<td>(note contraction is not always recommended)</td>
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<table>
<thead>
<tr>
<th>SB</th>
<th>Forward reach at neutral</th>
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<tbody>
<tr>
<td></td>
<td>(if picking up objects similar as MSB above)</td>
</tr>
<tr>
<td></td>
<td>Shoulder, elbow and wrist extension</td>
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<td>Bimanual tasks highly recommended (i.e. play with both hands)</td>
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| ECB | Elbow and wrist extension |
|====|---------------------------|
|    | Pronation and supination |
|    | Bimanual tasks using two beaters would be good |

Table 2: A summary of the recommended physical movements that are undertaken when playing the Musical Stress Ball (MSB), SoundBoard (SB) and Electronic Chime Bar (ECB) that may help with stroke rehabilitation of the upper limb.
health professionals, encouraging good movement and minimizing overcompensation

- Machine Learning: Allowing the system to calibrate thresholds to suit a wide range of physical abilities and allowing an increase in task difficulty over time

The project contributes to the field of HCI by suggesting that more research into stroke rehabilitation with computer based aids could have a significant impact on the number of options available to patients, thereby helping them to increase their time on physical exercises essential for rehabilitation. Of particular interest would be developing systems that are low cost and suitable for the home environment. In conclusion, to help improve the effective interaction between patients and computers it is important to develop systems that put the needs of the patient first.

References


