Body Perception Manipulation with Movement Sonification for Stroke Survivors Rehabilitation

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***Abstract*—Physical rehabilitation plays an essencial role in recovering from a stroke, but it can become repetitive and boring. We present an innovative sound-based prototype for real-time sonification of an upper limb exercise. The prototype is designed to engage stroke survivors in upper body exercises and influence their body perceptions. We ran a preliminary study with ten healthy participants to validate our sonification approach. Findings suggested that movement sonification has the potential for patient engagement and positively influences perceived body weight and capability. Moreover, the proposed approach holds promising results for future research with stroke survivors.**

***Index Terms*—Sonification; Stroke; Rehabilitation; Body perception;**

I. Introduction

Stroke has a significant impact on cognitive and motor abilities. Its incidence is expected to increase due to an ageing population and lifestyle changes [4], making stroke one the most significant burden to health and social care. In practice, the stroke survivors' brains "forgets" how to perform body movements, particularly upper-body movements (e.g., handshake, comb hair, wave), as the cells responsible for motor control/coordination die. Rehabilitation is a crucial process that aims to improve both the function and independence of stroke survivors by re-teaching functional movements [3].

However, the rehabilitation of stroke patients remains a challenge. The high demanding and repetitive nature of the activity requires patient endurance and engagement to overcome a tedious and often demanding experience [3]. Previous research has attempted to address these issues by leveraging sensing devices and providing motivating feedback, and however, these have focused mainly on visual feedback.

In this paper, we investigate motivating auditory feedback. Particularly, we aim to alter people's body perception and feelings during upper body exercises. We extend previous research that induced changes in perceived body weight by manipulating the auditory feedback of one's footsteps [5]. We build on this study by adapting sonification techniques (i.e., artificially built sounds) to upper body movements. We describe a prototype of an inertial measurement unit (IMU) and sonification techniques to influence users' body perception and feelings.

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We report on a preliminary user study with ten healthy subjects to investigate the feasibility and potential of using sound-drive body illusions to facilitate upper-body exercises. Results show improvements in patient engagement while positively altering body weight perception and perceived physical capability. These results illustrate the potential of body sonification to improve stroke rehabilitation programs.

II. System Overview: Altering Body Perception through Sonification

In our prototype, in figure 1, we enriched a commonly use therapy object, a dumbbell, with an IMU. The chosen exercise is the dumbbell hammer curl, a simple exercise that works the upper limbs. It is commonly used in stroke recovery to teach survivors motor skills to hold a glass and drink water autonomously.

The real-time auditory feedback was inspired by Ghai et al. work [2] and was generated using SuperCollider. Our sound synthesis was based on a sine wave oscillator, with amplitude and frequency modulated by angular velocity and pitch angle. Amplitude and frequency were chosen because they represent useful features easily identified by the listener, with amplitude being perceived as the loudness and frequency as the pitch. Following the studies that showed that different frequencies would influence body feelings in different ways [5], our sonification has two versions that differ in frequency ranges. The low-frequency ranges are between 100 to 1000 Hz, while the frequency ranges from 200 to 2000 Hz in the high-frequency sonification.

The prototype is composed of a dumbbell to which can be attached a Bitalino R-IoT IMU (including a triaxial accelerometer, a triaxial gyroscope and a triaxial magnetometer). The IMU sensor collects data from the movement in real-time; these data are transmitted to the sound synthesis software SuperCollider (in a PC). The produced sound is fed back to the user via headphones.

III. Preliminary study and results

The data presented herein were obtained in a preliminary user feasibility study with ten healthy participants (mean age 28.1 ± 9.6 years, seven male and three female, normal hearing). Their mean body weight and height were 70.2 ±

11.37 Kg and 173.2 ± 8.98 cm. Six participants reported they exercised once or twice a week, two participants reported they exercised three or more times a week, and two participants did not exercise at all.

Fig. 1. User testing our IMU based prototype

A within-subject study was performed and video and audio recorded. Each participant performed a training session using our prototype. Participants tested three conditions: **Control** (CC) - No Sound; **Low Frequency Sonification** (LFC) and **High Frequency Sonification** (HFC). In each condition, participants performed two trials of the exercise. In total, we had 10 participants x 3 conditions x 2 trials = 60 trials.

The following measures were considered: 1. **Trial duration** 2. **Perception of dumbbell weight** was assessed by including an open question in the post-questionnaire. 3. **Body feelings** were quantified using a questionnaire based on the one used in [5], Using 7-point Likert-type response to the range *speed bodyweight strength, capability, difficulty, and tiredness*. 4. **Emotional state**, using self-assessment manikin [1], assessing *Pleasure, Arousal and Dominance*. Each participant had to answer the post-questionnaire six times (after each trial). ANOVA was used to assess performance time (continuous variable) while the Friedman test was used for all the other variables (ordinal variables). Data are mean ± standard deviation unless otherwise stated. Results of our eleven dependent variables are: 1. **Performance time** (CC: 24.34 ± 6.57 s ; LFC: 24.85 ± 5.89 s ; HFC: 24.24 ± 5.38 s) with no statistically significant differences, F(2, 38) = 1.075, p = .351, 2. **Dumbbell weight perception** (CC: 1.21 ± .38 kg ; LFC: 1.08 ± .44 Kg ; HFC: 1.14 ± .33 Kg), e Friedman test revealed that the differences between conditions were not statistically significant, $\chi^2(2) = 3.160$, p = .206.; 3. **Body feelings and emotions**. The Friedman test only showed statistically significant differences for the *perceived body weight* ($\chi^2(2) = 8.759$, p = .013) and *perceived capability* ($\chi^2(2) = 9.333$, p = .009).

IV. Discussion

Previous research suggested that real-time movement sonification can alter users' behaviour, body feelings and emotions when performing physical activity. These findings showed that high-frequency sounds could make people move more dynamically and perceive themselves faster, lighter and happier. In contrast, low-frequency sounds can make people perceive themselves as slower and heavier. Based on these findings, we aimed to explore the effects of real-time sonification using a therapy object (enriched with an inertial sensor) instead of attaching it to the body. The developed work resulted in a real-time sonification of movement prototype that leveraged the previous findings that sound can manipulate body perception and feelings. In a within-subject approach study, we test our prototype with ten healthy people with three conditions (control, low-frequency sonification, high-frequency sonification). Even though our findings suggest that sonification can alter body perception and feelings, we did not obtain statistical significance for all studied measures. Only perceived body weight and perceived capability had statistically significant differences between the conditions. Users felt heavier and less capable when listening to the low-frequency sonification. These preliminary findings showed the potential of using movement sonification to influence body perception. However, our prototupe need further testing with stroke survivors.

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