REAL-TIME AUDITORY FEEDBACK OF ARM MOVEMENT AND EMG IN BICEPS CURL TRAINING TO ENHANCE THE QUALITY

Jiajun Yang

Audio Lab,
Department of Electronics,
University of York, UK
jy682@york.ac.uk

Andy Hunt

Audio Lab,
Department of Electronics,
University of York, UK
andy.hunt@york.ac.uk

ABSTRACT

In this paper, we describe the design of a sonification device using an electromyography (EMG) sensor and Mircosoft Kinect motion tracking camera to extract muscular and kinematic data while undertaking biceps curl exercise. A software platform has been developed using Max/MSP to convert acquired data into sonic feedback.

The system has been tested in a comparative user trial, with 22 participants being split into two groups. One group had the auditory feedback and the other did not. All participants completed a 3-session experiment on different days. We investigated whether the extra sonic feedback provides positive influence on both the exercise quality and training outcome.

Three parameters were analysed: movement speed, range of movement and total repetition effort. The results indicate that the sonification group performed consistently better than the other group except the movement range, which shows no improvement in both groups. They also indicate that sonification contributed the most to keeping a good steady pace of movement. Subjects in the sonification group also gave positive comments on the presence of sound, especially about distracting them from feeling fatigue.

This study underlines the potential of developing sonic interaction programmes for both general exercise and physiotherapy.

1. INTRODUCTION

In recent years, we have been seeing an increase in the variety of ways for presenting and interacting with computer data. This trend is seen in the increasing popularity of mobile computing devices and the newly introduced wearable devices. Companies such as Apple, Samsung, Nike, Microsoft have released fitness products incorporating body sensory devices. Still more products are under development and we assume that a new age of wearable devices is imminent.

Researchers have noticed a strong connection between the use of sound and the quality and extent of human body movement [1]. The most commonly used example is the use of music to assist rhythmically critical actions such as figure skating, dancing, etc. Sonification, serving as a method to objectively convey and interact with data through the use of sound [2, 3], has some advantages when used in assisting sport activities. Firstly, sound allows a screen-free situation, which enables users to focus more on their intended physical task, such as rowing [4] and jogging [5].

Secondly, music or sound can provide useful information for maintaining good rhythmic motor coordination and relaxation, and can lead to a positive mood and a raising of confidence and motivation [6]. In [7], researchers found the volume and tempo of music had effects on running speed, heart rate, and exercising arousal levels under a treadmill running condition.

Thirdly, sound is more attention grabbing than visual alerts when it comes to notification. This makes it superior in alarm situations [8]. In the same way, sound can be useful in improving sports movement that by notifying users if any changes needed to be made.

The structure of this paper is as follows: Section 2 gives an overview of the research hypothesis. Section 3 provides a description of the sonification system we developed. In Section 4, full details of the experiment are presented with the results and analysis. Section 5 covers the analysis of subjects' comments. Sections 6 & 7 draw conclusions and discuss the next stage of the research and its prospective as a commercial product in the future.

2. RESEARCH OVERVIEW

In this study, we hypothesized that by listening to real-time auditory feedback of healthy adult's muscle activity (during biceps curls) along with kinesiological data, subjects will have better exercise performance and progress than those who do the same exercise without real-time audio feedback.

We envisaged that sonification could serve as a virtual training supervisor that provides instant feedback on the movement itself as well as notification sounds to correct any movement deficiencies.

The criteria of the sonification are:

- Reflective: The sonification should directly reflect the movement being performed.
- Suggestive: The sound should be capable of reminding the user about the quality of the exercise. It should also suggest where the user could make changes if necessary.
- Listening experience: the sound also should be interesting to listen to or at least have sufficient variation to prevent boredom.

3. SYSTEM DESCRIPTION

Based on the research hypothesis, a sonification system has been developed featuring both sensory devices (hardware) and a software platform. This section presents the design of the sonification system.

3.1. Hardware

The muscle's activity and the kinematic data of hand movements are chosen as inputs to the sonification mapping. Two types sensors are used accordingly.

For muscular activity, a surface EMG (electromyogram) sensor is used to extract myoelectric signals directly from the active muscle. The EMG signal is a direct reflection of the muscle current level of activation. EMG is widely used in the study of postural tasks, functional movements and training regimes [9].

A wearable EMG belt was designed (see Figure.1a), consisting of an EMG sensor [1], an Arduino Duemilanove microprocessor and a Bluetooth modem. The EMG signal is sent to computer via the Arduino at 9600 baud.

Figure 1 a) EMG Belt (Left), b) Kinect Camera (Right)

For limb position extraction, a Microsoft Kinect (Figure.1b) camera was placed in front of user. A tracking program named Synapse[2] was used to acquire 2D coordinates relative to the center of the subject's torso and to transmit the coordinates via Open Sound Control (OSC). The reason for using relative coordinates is to provide consistency regardless of the position that the user stands within the visual frame.

3.2. Software

The software platform (see Figure 2) was developed using Max/Msp, and has 3 main functionalities.

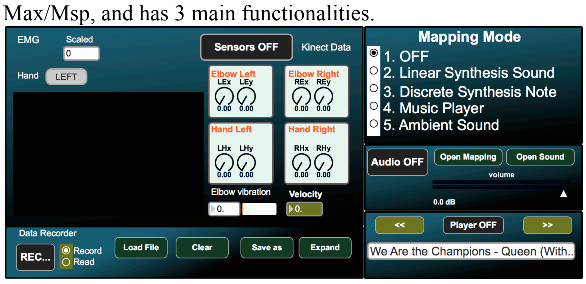

Figure 2: Main interface of the sonification software

(1) **Data management**: This section handles bio-signal acquisition. The sampling rate for the data recorder is set at 50Hz, because biceps curls are relatively slow action exercises (typically less than 1Hz). Therefore, being able to output 50 sets of data (coordinates, EMG, speed, etc.) per second is more than enough for both sonification and analysis purposes. This part of the program also handles basic analysis of the data, such as finding the rate of change (v) of the y-coordinate and the dynamic range of the movement (difference between the lowest and highest y-coordinates of the hand).

(2) **Sound engine** featuring a subtractive/FM synthesizer and an audio sampler. In order for the sound to distinctively represent the movement and muscular activities, the following 5 parameters are controlled by the bio-signal in different combinations. They are: loudness, pitch, filter cut-off frequency (brightness), noise level and sample playback speed.

To avoid boredom in long-term use, four types of sounds are available to choose from:

- **Linear frequency synthesis**

This preset produces a synthesised sound with a linear pitch variation during the biceps curl. The sound itself comprises a sawtooth waveform and a triangular waveform, resulting in a rich spectral content. The pitch is linearly controlled by the current vertical position of the hand with a valid frequency range from 0Hz (lowest hand position) to 620Hz (highest position). The amplitude of the EMG signal shapes the brightness of the sound through a linear mapping to the cut-off frequency of a band-pass filter. The overall sound characteristic was described as 'sci-fi' by some of the users. In additions, a white noise will be triggered if the movement velocity is over a threshold value, thus encouraging the exercise to be taken at a slower pace.

- **Discrete bell-like sound**

In terms of the timbre, this preset is spectrally simple. The vertical hand position triggers a range of notes between C4 and E5. The vertical range is divided into 10 equidistant sections. When the y coordinates moves from one section to another a new note will be triggered. To avoid boredom, the note selection varies each time based on two Markov chain probability matrices. One is used in biceps contraction (moving up) with an ascending note progression and the other is used in biceps extension (moving down) with a descending note progression. The same white noise as above is used as a warning to slow down.

- **Music player**

This mode allows users to upload their *own* music files and have them played back during exercise. The EMG signal is used to control the brightness of the sound via a low-pass filter. Thus the more activity generated from the muscle the greater the clarity in the music. This is to encourage users to work hard to hear good quality music. If the user moves his/her arm too quickly, the pitch of the right channel is altered so that the music does not sound 'correct'. This is used as a warning or a penalty if the user is moving too quickly. The incorrect effect only lasts for one repetition and will then be reset to normal pitch.

- **Ambient sound**

This also uses the sampler as above, but triggers the sound of a soft breeze blowing during the exercise. It aims to create a relaxing sensation for the user rather than giving precise feedback on the movement. The EMG signal is mapped to control the cut-off frequency of a low-pass filter so that wind sounds 'harsher' when more effort is put in. The speed warning

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[1] Purchased from http://www.advancertechnologies.com/
[2] http://synapsekinect.tumblr.com/

is replaced by a sine wave beep instead of white noise, which would be hard to hear in the noise-based soundscape.

(3) **Mapping engine**: manages the data connection between the bio-signal and the sonic parameters. The sound presets are stored and changed in this patch. Parameter mapping [2, 3] is used as the main mapping method.

If more hardware details are required, please refer to the previous paper of this research, which focused on the user experience of different types of auditory feedback [10].

4. EXPERIMENTATION & DATA ANALYSIS

The sonification system was applied in the comparative trial. Full details are described in the following sections.

4.1. Experimental Setup

The experiment was carried out in the Audio Lab, University of York, U.K. 22 people participated: 19 males, 3 females. A laptop was used with the sonification software installed. Auditory display is via a pair of speakers.

Subjects were randomly assigned to one for the two groups: *sonification group* and *control group*. Auditory feedback during the exercise was given only to the sonification group.

The experiment involved three sessions on different dates. In each session, participants were asked to select a dumbbell, whose weight was challenging for the subject's own standard. All three sessions involved the same type of exercise. Yet participants had control of the quantity of repetitions and sets as a factor of studying progression and participants' motivation of exercise.

Figure 3. Demonstration of the exercise

Prior to the exercise, subjects were briefed (and shown a demonstration) that there are *three quality criteria*:

(1) Aiming for a large movement range, which means trying to lift the dumbbell as high as possible and when lowering the dumbbell trying to return to the natural straight-arm position.
(2) Aiming for a slower pace. The ideal speed for each direction (up or down) of movement is at least 2 second.
(3) Subjects are free to do whatever amount of exercise they feel comfortable with but the more the better.

Participants in the sonification groups were also demonstrated the four different sound presets and they are allowed to choose any of the presets based on their own preferences. After each session, all subjects were asked to fill in a survey to express their tiredness and comment on their experience.

The following data were recorded

(1) **Normalised EMG**: Due to differences between different subjects' biceps, some might have a larger range while others might have smaller. Therefore, in order for all users to be able to achieve a full control range, calibration is required based on subject's rest-stage EMG and the maximum contraction EMG then scale this range to a control range of 0 to 1023.

(2) **Active hand y coordinate**: This parameter reflects the vertical movement (relative height) of the active hand.

(3) **Velocity of y coordinate**: The rate of change of the y-axis coordinate. Positive velocity indicates biceps contraction whilst negative velocity indicates biceps extension.

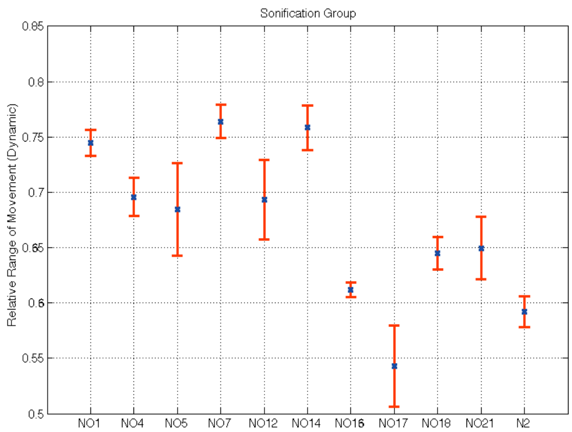
(4) **Dynamic of y coordinate**: The difference between the highest y coordinate and lowest y coordinate in each repetition.

4.2. Experimental Results and Analysis

Three dependent variables were collected in the experiment. They are movement range, movement velocity and effort. This section presents discussion on each variable then follows with an influential statistics section.

4.2.1. Movement Range

The *movement range* is the distance completed in a repetition. The distance is the vertical coordinate difference between straight-arm hand position and peak-hand position when lifting the dumbbell. The coordinate is ranged from 0 (straight-arm position) and 0.8 (shoulder position) and 1.0 (top of the head). Referring to the quality criteria in 4.1, subjects should aim for a large movement range. Figure 4 demonstrates the average dynamic per repetition of each participant from all three sessions (the sonification group being shown at the top and below that the control group).



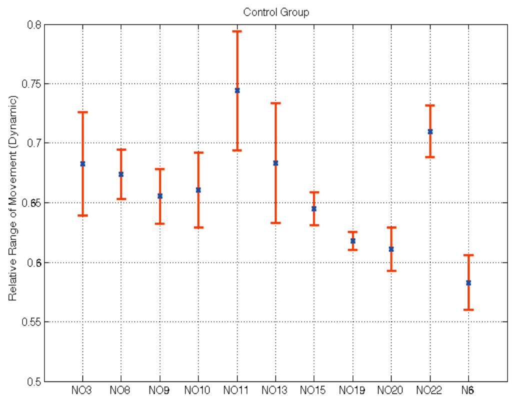


Figure 4. Movement range comparison (blue crosses are the mean movement ranges, error bars are the standard deviations)

For the group performance, the mean movement range for the sonification group and control group are 0.67 and 0.66 respectively. According to the graph, surprisingly, the control group performed more stably than the sonification group. The standard deviations of the mean movement range between groups are 0.07 (sonification) and 0.04 (control).

Although the sonification provided reference to the vertical position of the subject's hand, it did not contribute to any variation in exercise quality. During the experiment, the researcher observed that 3 participants in the sonification group did not achieve a good movement range. They either started another repetition without completely lowering the forearm or did not reach the top possible position. It appears that tired subjects do not use the sound to maximize their movement range. This may be because they are not explicitly warned that their movement is falling short of the maximum.

4.2.2. Movement Velocity

This data represents the average velocity (vertical coordinate change per second) per repetition in a session. Based on the quality criteria in 4.1, a lower velocity value is considered to be better quality.

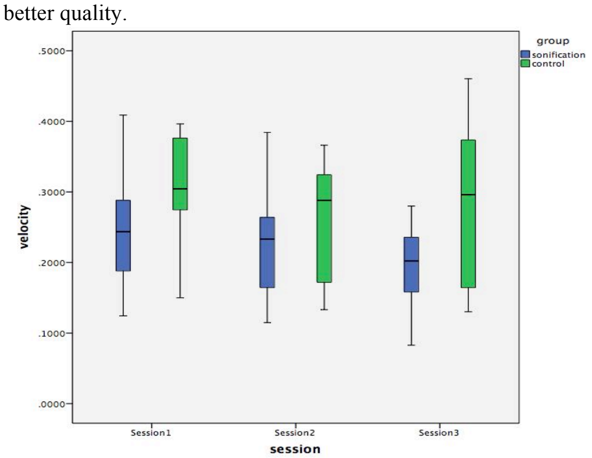


Figure 5. Average velocity comparison

This is the most influential attribute out of the three dependent variables as sonification showed its superiority in maintaining a slow pace of the exercise (see Figure 5). The boxplot suggests that, overall the sonification group had a lower velocity value. The sonification group also improved consistently throughout the three sessions. Yet without audio feedback, subjects in the control group tended to exercise much quicker even though a demonstration was shown at the beginning of the first session about the criteria of exercise. The extra sonic cue seems to have served as an active *reminder* of the speed of movement.

4.2.3. Total effort

Prior to the experiment, we compared the mean weights of the dumbbell selection. They are 5.0kg (sonification group) and 4.7kg (control group). Therefore, we treated the initial mean dumbbell weights as approximately equal (6% in difference). The total effort is a combination of the weight of dumbbell and the amount of repetitions. It is calculated as the equation below,

$$effort = w \cdot r$$

where w is the weight, r is the repetitions. The results in three sessions are shown in Figure 6. There is an increase in the medians of the sonification group. In all sessions, the sonification group is noted with both higher upper quartiles and median values although the lower quartiles are very similar.

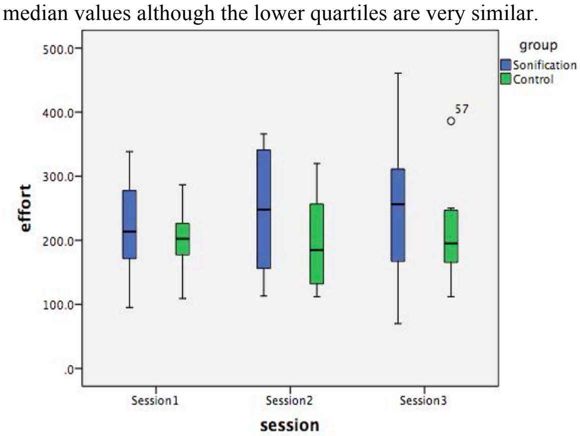


Figure 6. Total effort comparison

However, it should be noted that the experiment only lasted for 3 sessions whereas generally weight training requires a longer time to show clear improvement in muscle strength. The difference between two groups is not significant enough to make a judgment that sonification can definitely lead to a quicker improvement in exercise quality than the control group. Yet, the results underline a possibility that if subjects enjoyed listening to the sonic feedback the motivation improved, which caused a better improvement in the amount of repetitions completed.

4.2.4. Influential Statistics

A one-way multivariate analysis of variance (MANOVA) was conducted using the abovementioned three dependent variables for the final session between two groups. It aims to investigate the difference in the overall exercise quality between two groups. No serious violations were found in the preliminary assumption testings, including normality, linearity, univariate and multivariate outliers, homogencity of variance-covariance matric es. There is no statistically significant difference between sonification group and control group on the combined dependent variables, F(3, 18), p = .161 (Wilk's Lambda), partial eta squared = .244.

When the dependent variables results were considered seprately, we found a significant difference of the velocity, F(1, 20) = 4.934, p = .038 and partial eta squared = .198. This dependent variable has a large effect size (19.8%) . The results show that sonification group has a slower movement velocity (M = .191) than control group (M = .279). The results indicate the sonic feedback serves best at reminding the speed of movement in order to achieve slow and steady exercise movements.

5. QUALITATIVE RESULTS

Comments have been gathered from the sonification group about the use of sonification. 8 out of the 11 subjects expressed that the sounds they received had a positive effect on their exercise. 2 participants in the same group did not make any comments of the sonic feedback and one expressed that he did not enjoy it.

The following is some of the comments made by the participants:

"I enjoyed the sound"

"I tried to avoid the over-speeding sound"

"The sound distracted me from feeling tired" – Three participants expressed that the sound served as a distraction from fatigue. This is also supported by [11].

"It felt annoying at first but later it kept me going."

"I think the sound is getting clearer comparing to the last session."

"Personally I wouldn't listen to this while I was exercising." – Two participants mentioned that they did not enjoy the sound at all and felt it sound very noisy to them (both used the linear synthesis sound preset).

"I just felt very tired"

These comments indicate that the sonification feedback provided a mostly positive effect on both providing training guidance and general experience. It is reasonable that some people may find the sound uncomfortable to listen to. It pinpoints a fact that the current sound design consideration is still biased to being informative and not enough effort was put into accommodating different aesthetic preference. We believe with careful fine-tuning the sound aesthetic can be improved in order to provide a better experience.

6. CONCLUSION

In this research, a sonification system was designed for providing real-time feedback of subject's physical exercise. A latitudinal experiment was conducted to compare the exercising quality between a sonification group and a control group (no sound feedback) over a three-sessions period. The exercise quality was monitored regarding participants' movement speed, range and the total effort.

The study shows that sonification group performed consistently better in terms of movement velocity and effort, but there is no difference in the movement range. Although MANOVA analysis shows there is no significant difference between two groups in session 3 considering the combined dependent variables, significant result was found in movement velocity with a large effect size, indicating that the sonification a strong influence on maintaining a slow biceps curl speed. Although there is no significant result in the total effort, the post-session survey concluded that most participants in the sonification group found the auditory feedback to have positive effect on their actions.

We believe that the sonification device has the potential to be further improved and eventually developed into a sophisticated product to improve the general quality of physical exercise.

7. FUTURE WORK

At the time of submitting this paper, a crossover experiment has been carried out to study the difference between doing biceps curl with and without sonification feedback in different phases.

With the new age of wearable device and the technology focus on fitness and health, an exciting period is waiting ahead. This project has the potential to contribute to the field of fitness assistive devices and thus to encourage more people to do regular physical exercise to a relatively good standard. As for the system, although it is still in its prototype stage, it can be developed into a smartphone add-on, offering convenient accessibility to users.

Another possible extension of the project is to facilitate the sonification system in rehabilitation training. In this context sonified bio-feedback could be used to monitor and correct the patient's prescribed exercise.

8. ACKNOWLEDGEMENT

We would like to express our sincere gratitude to all the participants who took part in the experiment.

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