SONIC TRAINER: REAL-TIME SONIFICATION OF MUSCULAR ACTIVITY AND LIMB POSITIONS IN GENERAL PHYSICAL EXERCISE

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ABSTRACT

The research outlined in this paper uses real-time sonic feedback to help improve the effectiveness of a user's general physical training. It involves the development of a device to provide sonified feedback of a user's kinesiological and muscular state while undertaking a series of exercises. Customised sonification software is written in Max/MSP to deal with data management and the sonification process with four types of sound feedback available for the participants.

In the pilot study, 9 people used the sonification device in a 'biceps curl' exercise routine. Four different sonification methods were tested on the participants over two sessions. Clear improvement of the movement quality was observed in the second session as participants tended to slow down their movements in order to avoid a noise alert. No obvious improvement in the physical range of movement was found between these two sessions. The participants were interviewed about their experience. The results show that most participants found the produced sounds to be informative and interesting. Yet there is room for improvement mainly regarding the sound aesthetic.

This study shows the potential of using real-time interactive sonification to improve the quality of resistance training by providing useful cues about movement dynamic and velocity. Suitable sonification algorithms could help to improve training motivation and ease the sensation of fatigue.

1. INTRODUCTION

The movement of the human body often produces acoustic energy. We can gain information about that movement by perceiving motion-related sounds. For instance, the loudness of a badminton racket swing can reflect the strength and speed of the swing.

Effenberg describes the relationships between music and sport as 'interwoven' [1]. Music is an essential part of many rhythm-driven sports, such as figure skating and synchronized swimming, both for aesthetic and informative reasons. Also, many people like to listen to music while doing physical exercise. Apart from simply enjoying some favourite music the sound itself provides useful cues for maintaining good rhythmic motor coordination and relaxation, and it can also lead to a positive mood and a raising of confidence and motivation [2, 3, 4].

Computer technologies have traditionally used visual displays, and so data analysis has been carried out with graphical techniques. The relatively recent development and study of auditory display techniques, conveying information through the use of sound objectively [5], provides us with new opportunities for analysing data and feeding back information to human users.

There are many advantages to using sound to study and interact with data. Firstly, sound allows a screen-free scenario which enables users to focus more on their main physical task. For instance, an auditory monitoring system can help anaesthetists to improve their working efficiency during an operation, as it reduces the mental workload of having to focus on visual monitors while carrying out many other responsibilities [6].

Secondly, sound shows its superiority in attracting people's attention. A visual alert may be easily neglected if a person's visual attention is focused elsewhere. However, sound is highly suitable for alarm systems because not only can it attract people's attention while they are looking elsewhere, but the sound itself can carry extra implicit information, e.g., "this is a fire alarm; leave now" [7].

In the domain of general physical exercise, such as free weight training, there is a common problem that many people tend to focus more on quantity rather than quality. People in a gym are likely to carry out a certain number of repetitions without as much regard for the smoothness of the movement or the way that sets of muscles are activated. This problem is compounded when exercising at home, because of the absence of professional trainers. Although this may not seem much of a problem to general public, it becomes immensely important for patients who require physiotherapy treatment following an accident or operation.

This paper considers how we can help people to improve the quality of their physical exercise by introducing auditory feedback to their exercise routines. The research has potential applications in daily physical exercise, elite sport or physical rehabilitation. Artificial auditory signals can be generated based on the user's real-time movement, using computer technology to play the role of a virtual trainer, by guiding the movement and potentially leading to an improvement of the exercise. Hence, we present a sonification system that provides real-time auditory feedback of a user's exercising movement as a tool aiming to help improve the quality of the training.

In this pilot study, the main aim was to investigate subjects' experiences in four different sonification modes, and test how these four modes of sonification influence the exercise quality across two identical sessions. As such it did not include a control group, but a control-based comparison experiment will be conducted in the future research as explained later in this paper.

The structure of this paper is as follows: Section 2 demonstrates the concept of interactive sonification referring to literature about sonifying human body movement. Sections 3 and 4 present an overview of the sonification system we have developed, with the usage demonstrated in Section 5. Section 6 contains the procedure, results and implications of a pilot study. Finally Section 7 discusses further work and potential extension of the work done so far.

2. SONIFICATION OF HUMAN BODY MOVEMENT

Sonification is a subset of the area of auditory display. It is defined as the interpretation and transformation of data into perceivable non-speech acoustic signals for the use of conveying information [8]. Interactive sonification serves an additional purpose which allows the manipulation of data based on the sonified feedback. In this research, we hypothesise that sonic feedback can serve as a real-time training quality monitor and motivator to help maintain a good quality of exercise.

The research concept is concerned with whether we can expand the richness of naturally occurring acoustic cues by producing artificial sonic feedback to give extra information about the quality of the exercise to the user, in order that they can make appropriate adjustment in response.

Vogt et al. [9] developed PhysioSonic in 2009, using a camera tracking system with markers placed on a user to study shoulder movement and provide both metaphorical and musical audio feedback. The system motivated patients with arm abduction and adduction problems via the synthesised or sampled feedback. Kleiman-Weiner and Berger [10] developed an approach to sonify the motion of the arm to improve the action of a golfer's swing. Barrass et. al. [11] studied how different sonification methods performed in outdoor jogging. Other researches on the sonification of human body movement can be found in [1, 14, 15, 12].

Two types of bio-information were sonified in this study. Firstly, the visible kinetic aspects of the movement were captured using a Microsoft Kinect system. Such visible motion reflects the most straightforward impression of movement quality, such as displacement, dynamics and speed. There are also hidden attributes such as strength, which is harder to observe visually. Strength, effort and tension are generated from within the muscles and therefore this requires a more direct and dedicated muscle measurement system, for which we use an electromyography (EMG) sensor.

When a muscle is activated, muscle cells produce electrical potential. The resultant electrical signal can be detected by EMG sensors. EMG is widely used in the study of postural tasks, functional movements and training regimes [13]. Pauletto and Hunt sonified EMG data from leg muscles in 2006 [14]. They developed an alternative way of portraying the data from EMG sensors using sonification instead of a visual display. EMG sonification can also be seen in [15], where muscular activity of a timpani player's performance was sonified.

The following section explains the construction of the sonification device, which is capable of extracting both kinetic and muscular data in real time. A diagrammatic overview of the system is shown in figure 1.

3. SONIFICATION SYSTEM - HARDWARE

Two types of sensory devices are used to capture arm movement and muscular activity separately. The first is a Microsoft Kinect sensor (fig. 2) to capture real-time limb movement in a format of 2D coordinates (left-right, up-down) related to the centre of mass. The frame rate is 30fps. Extrapolated from the basic coordinates, we also calculate the vertical component of the velocity, which is a key indicator for the biceps curl exercise quality.

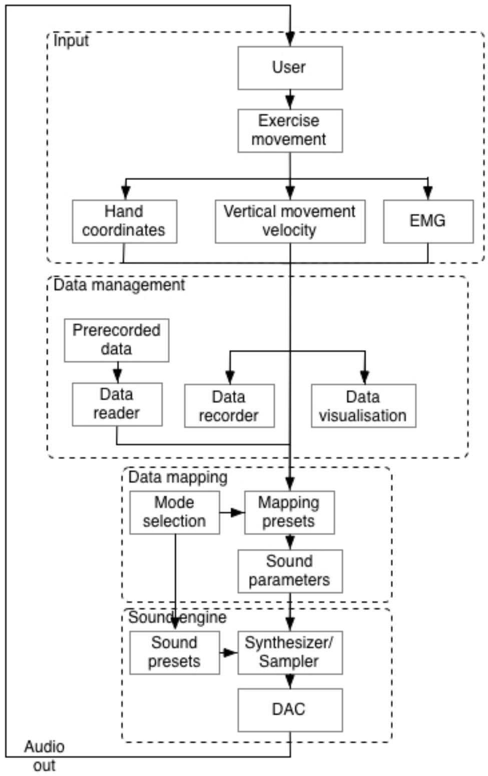

Figure 1: *Physical exercise sonification system*

To measure the muscular activity, a wearable EMG belt shown in fig. 3 was designed to manage the myoelectric signal acquisition and wireless transmission to the computer. This belt comprises an EMG sensor unit[1] powered by two 9v batteries, an Arduino Duemilanove microprocessor (9600 baud) and a Bluetooth modem.

4. SONIFICATION SYSTEM - SOFTWARE

The sonification software (fig.4) was developed using Max/MSP[2]. It consists of three main functions, described in the following paragraphs.

4.1. Data management

The data management section handles EMG data and Kinect data acquisition through serial communication (sampling rate 500Hz) and the Open Sound Control (OSC)[3] protocol. The EMG device introduces a baseline offset of approximately 0.170.03v (signal ranges between 0 to 5v). Hence, baseline adjustment was used to remove the offset. In order to give participants a more obvious alteration in sound between muscle rest state and contraction state, EMG normalisation was also used to ensure all users benefitted from the full range of data mapping. A data recorder was

[1]http://www.advancertechnologies.com/
[2]http://cycling74.com/
[3]http://opensoundcontrol.org/

Figure 2: Kinect motion capture camera

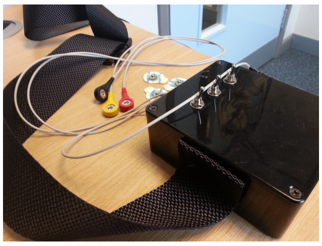

Figure 3: EMG sensory belt

used to store all the bio-information into a text file. Hence, bio-information can be sonified or studied either in real time or offline. In addition, plots of the Kinect and EMG data are shown graphically. Kinect data - in the form of the positions of body joints - is presented through several knobs (for display only) shown on the right side of fig.4. The Kinect data acquisition allows a total display of up to 15 body joints, however only a few were numerically displayed in real time to make the display more compact. The EMG data can be monitored through the oscilloscope on the left side

4.2. Sound engine

The sound engine is designed separately and is linked with the main interface through the data mapping patch, (explained in 4.3). Hence, it is not graphically displayed on the main interface while the system is in use. The sound engine consists of a subtractive synthesizer and an audio sampler. Theoretically, every parameter in the sound engine can be controlled by the movement data. However, in practice, only a few parameters have been chosen for the control (based on some initial tests) in order to produce the most distinguishable acoustic results. These parameters are: loudness, pitch, filter cut-off frequency (brightness), sample playback speed and noise level.

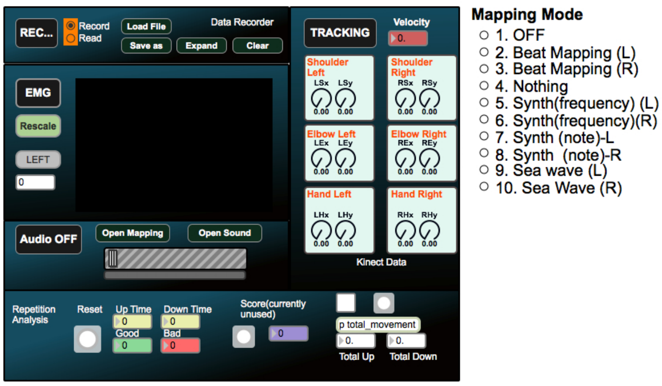

Figure 4: *Main interface of the sonification software*

For the sound design, we customised four sonification mapping schemes for the pilot test with different acoustic textures and responses. These four schemes are selectable by the user. The assumption was that the majority of intended users would not have a background in audio synthesis or programming, so a selection from pre-sets was the best way of presenting a choice.

- Linear Frequency Synthesis Sound Mode
  In this mode, the synthesiser is set to produce a sound with rich spectral content. It consists of a combination of triangular and square waves. In terms of the mapping, the current vertical position (low to high) of the hand is mapped to a linear scale of frequency (valid frequency: 20 to 570Hz). The velocity of movement is set to trigger a white noise sound when it exceeds a threshold value, which notifies the user of movement that is too fast. The use of noise for this notification helps to distinguish the 'speeding' indication sound from the main sonic feedback. To avoid annoyance, if the noise sound occurs too frequently due to bad quality of movement, the white noise is softened by using a band-pass filter and an amplitude envelope with a slow attack time.
  The EMG signal is mapped to the cut-off frequency of a band-pass filter. This mapping allows the EMG data to affect the brightness of the sound. Larger EMG values (indicating more muscle power) lead to a brighter and clearer tonal quality.
- 'MIDI Note' Synthesis Sound Mode
  The same timbre and mapping scheme are used as the previous mode. Yet instead of playing the sound with a linear pitch change, the full vertical range of arm movement is divided into 10 sections. Each section plays a note on the synthesiser which is quantised in pitch to an equal temperament scale in the range of C4 to E5 with fixed velocity and length. To avoid boredom for the listener, the note selection is not fixed, but based on two customised first order Markov chain probability tables. This means that the current note is selected based on the previous note. Considering each note as a state, each state will generate one of only a few other states. For example, when the current state is C4, the next state has a 45% chance to be D4, 25% chance to be E4, 10% to remain the same note and 20% chance to be E4. Therefore, tonally, this will result in a similar (but different) progression of notes in each set of movement. Different melodic patterns are played according to the direction of the arm movement. Contraction of the biceps results in an ascending melody while extension produces a descending pattern. The melody is different each time because of the probability tables.
- Rhythmic Sound Mode
  This mode emits a rhythmic arpeggiator loop when the user starts moving the forearm to a certain height. Then the loop will keep playing along with the movement until the user's forearm is back at the original height level again, indicating the completion of a repetition. The purpose is to help the user scale the timing of a full repetition to match the full length of the musical loop. The white noise sound is again used as an indication of moving too fast.
- Ambient Sound Mode
  Similar to the rhythmic mode, this triggers a sample of sea waves instead. It aims to create a relaxing sensation for the user rather than giving precise information on the movement. Because of the richness in the spectrum of the sound, playing a noise as a warning for moving too fast becomes hardly audible as it is masked by the ambient sound. Therefore, the noise was replaced by a sine wave beep.

Audio examples can be downloaded, see section 8.

There are two main reasons for providing multiple types of sound for the same movement set. 1) People have different personal preference for sounds. Therefore, consideration needs to be given about how to provide sonic options for each user. 2) Each mode type has its own emphasis in terms of providing sonic feedback. The linear frequency can represent the most straightforward vertical displacement of the hand. The MIDI mode focuses more on reminding users to slow down their movements, in order to generate a measured progression of a melodic pattern. The rhythmic mode aims to improve the steadiness of the movement, whilst the ambient mode aims to help users to relax.

Audio examples can be downloaded in the footnote below [4].

4.3. Data mapping

The final major functionality is the mapping patch, which links the bio-information from the data management section with various sound parameters from the sound engine such as pitch, filter cut-off frequency, volume, etc. Parameter mapping [5, 8] is used as the main mapping method. The EMG data and Kinect data are scaled appropriately in the patch in order to result in the correct range of values to control the sound parameters.

5. HOW TO USE THE SYSTEM

The user wears the EMG belt and has electrodes placed on the skin surface directly over the dedicated muscle, in this case the biceps. Technical details of the electrode placement are not included in this paper; for more information, please refer to [13]. The user also stands in front of the Kinect sensor, facing towards it. When the device is activated the user can hear sounds being generated according to their arm movement.

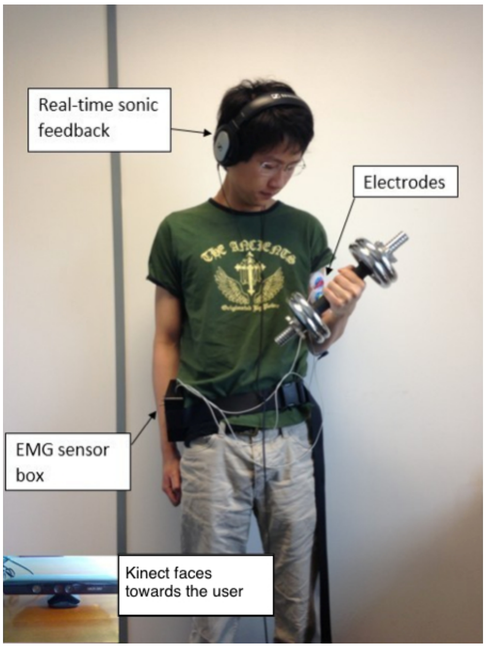

Figure 5: *Demonstration of using the device*

[4]https://sites.google.com/a/york.ac.uk/jiajun/shared-files

This paragraph describes a set of benchmark data recorded from a regular gym trainer. As shown on fig.6, the position changed smoothly and slowly (approximately 8 seconds per repetition). Within each repetition, in muscle contraction, the EMG signal rose slowly and peaked at roughly the highest vertical position. Then in muscle extension, there is another small EMG peak indicating the subject tried to prevent the dumbbell from lowering too fast.

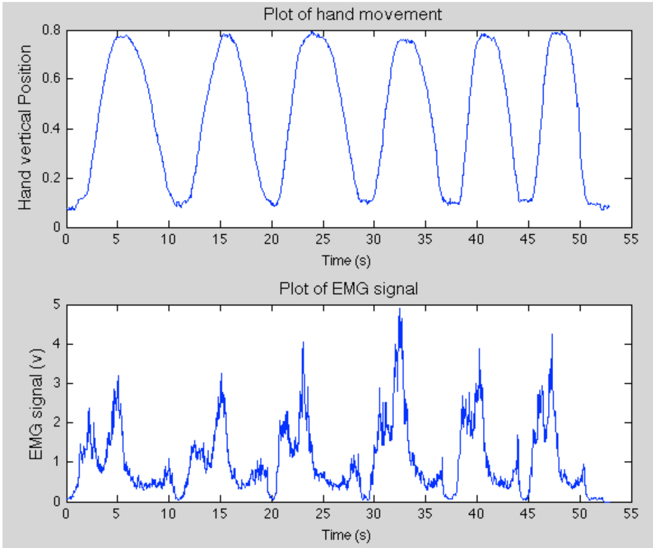

Figure 6: *Hand vertical position and EMG signal of a set of good quality movement (benchmark)*

6. PILOT STUDY AND DISCUSSION

6.1. Overview

The purpose of the pilot study was to examine the use of the device and to gather user experience and suggestions. We also gained an initial impression on how this sonification system can influence the user's body movement during biceps curls by interviewing participants after their exercise sessions.

Nine participants (all male, mean age 25.8 ± 3.0)were recruited to participate in a test made up of two sessions. In each session, participants were asked to do four sets of dumbbell curls with one of the four sonification modes played in each set. Participants were told to listen to the sonic feedback and try to respond to the sound while exercising. Each participant experienced all four sonification modes and therefore we could study their relative experience of each via a post-session interview. Their Kinect and EMG data were both recorded for offline sonification study and analysis purposes.

We defined a good quality of exercise as consisting of the following two criteria: 1. The maximum dynamic range of movement possible, which means that the forearm should aim to reach the lowest and highest positions while the upper part of the arm remains still. 2. The concentric and eccentric contractions should be executed at a steady and relatively slow speed, with a total of 4 to 8 seconds per repetition. This has been shown to help improve blood flow which can lead to a better training results [16].

6.2. First Session

At the beginning of the session, a copy of the consent form was given to the participant to sign and the purpose and procedures of the test were clearly explained. An adjustable dumbbell was prepared and the participant could adjust the weight by adding or removing plates to the two sides of the dumbbell.

The participant was then fitted with the EMG device and positioned to stand in front of the Kinect sensor. A set of Sennheiser HD 201 headphones was provided for the participant to listen to the sonification. Prior to the session, a trial was conducted to give the participant some familiarity with the exercise and the resultant sound.

During the test, participants did several sets of exercises, each with a different sound mapping. The repetition quantity in each set was entirely up to the participant to decide upon, based on their own motivation and physical condition. 1-2 minutes rest was given between each set. After the session, a copy of the questionnaire was given to the participant and they were asked to rate each sonification mode in terms of its comprehensibility and preference from an integral scale between 1 to 5 (very poor, poor, moderate, good, excellent). Each participant was also asked to comment on the experience of using the device with each mode. Comments were recorded either orally at the session or in written form.

6.3. Second Session

In the second session, participants were asked to complete the same four sets of biceps curls with the same sonification modes. After the session, participants again rated the four sonification modes. The reason for conducting an identical second session is because, at the first session, a participant may have been unfamiliar with the whole process and found the sounds strange to listen to. Therefore, we looked for any difference in both the exercising quality and subjective opinions of the sonification, after they became more familiar with the sound and system.

6.4. Quantitative Results

Figure 7 shows the plots of both EMG signal strength and the hand's y coordinate (dumbbell height) during a set of repetitions using the linear frequency mode. The EMG data was normalised (0 to 1.0) so that it could be viewed more easily together with the y coordinate. Peaks in the EMG signal can be seen to be occurring during vertical lifting, which is what would be expected, but also in the lowest part of the movement, where the dumbbell is being decelerated.

Figure 8 represents the velocity progression of the same set of repetitions as the previous graph. We defined a velocity threshold of $v_t = \pm 0.78$ whereby the white noise would be sounded if the absolute velocity $|v|$ was greater than v_t.

The mean movement dynamic range and mean repetition time gathered from the participants' two-sessions of exercise were analysed. We had hypothesised that an improvement of mean dynamic range and repetition time would be found in the second session as participants gained familiarity with the system.

In terms of the mean dynamic range, such improvement could not be statistically supported (table 1). A paired-samples T test shows a significance level with $p = 0.191$ and a low correlation of 0.138. However the table demonstrates that for several participants there was indeed an improvement from the first session to the second.

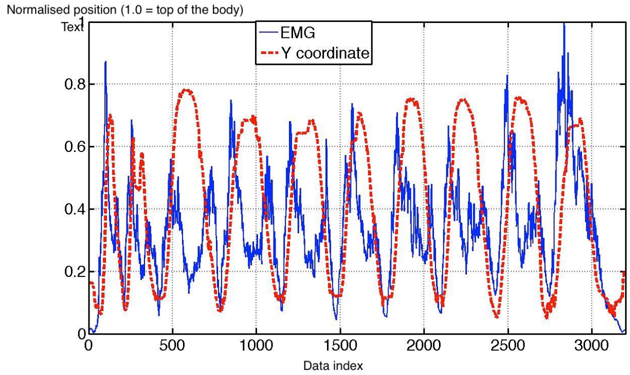

Figure 7: *EMG and dumbbell height plotted together*

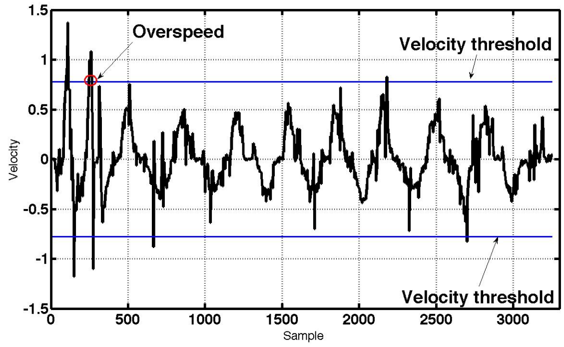

Figure 8: *Changes of hand velocity throughout a whole set of movements using the linear frequency mode.*

The same test was conducted to study for the mean repetition time. The result shows a significance level with $p = 0.003$, and an average increase in the repetition time of 1.58 second.

The different extents of improvement can be seen from table 2. Slower movements were executed in the second sessions for all participants, (remembering that in curls, a slow and steady movement is desired as opposed to a fast and spiky movement). During the second session, no extra instructions were given to the participants. Therefore we did not purposely introduce factors that may have led to a change of curl velocity. Two participants (No.2 and No.5) made the least improvement on average time per repetition with only 3% and 5% increment respectively. Yet the mean repetition time of participant 5 already lies in the high standard range. A greater amount of improvement was achieved by the other participants.

6.5. Qualitative Results

The questionnaire collected subjective opinions of participants' experience. Participants rated each mode in terms of the comprehensibility and preference from a scale of 1 to 5, where 1 means 'highly disliked' and 5 means 'highly favoured'. The results show a moderate overall rating (across all four modes) in comprehensibility and preference with 3.71 and 3.41 out 5 respectively. As shown in table 3, on average, participants found that the linear frequency mode delivered a better sonic representation of the curl

Table 1: Mean Dynamic per Repetition

Participant	1st Session	2nd Session	Differences
1	1.247	1.653	+33%
2	1.569	1.450	-8%
3	1.235	1.693	+37%
4	1.586	1.531	-3%
5	1.558	1.480	-5%
6	1.512	1.524	+1%
7	1.399	1.539	+10%
8	1.650	1.791	+9%
9	1.265	1.255	-1%

Table 2: Average Time per Repetition (unit: second)

Participant	1st Session	2nd Session	Differences
1	3.23	6.85	+121%
2	3.58	3.75	+5%
3	4.26	6.73	+58%
4	5.50	6.99	+27%
5	7.45	7.66	+3%
6	3.11	4.01	+29%
7	4.66	6.24	+34%
8	7.37	9.48	+29%
9	3.78	5.42	+43%

compared to the others. It scored 4.22 on mean comprehensibility with a standard deviation of 1.31. The majority of participants found this mode sufficiently informative and only one participant thought it was confusing. The rhythmic mode seems to be the least informative among all four. This may be caused by the specifics of this mode's mapping; the vertical movement only control the initial activation of the sound – once activated the sound plays independently until the position is back to the initial level (where the arm is in a natural straighten position). The movement does not alter the sound greatly apart from the brightness changes due the change of the EMG data. Therefore, participants generally felt less in control over the sound.

Table 3: Mean rating and standard deviation of four sonifications

	Comprehensibility		Preference	
Mode	Mean	Std	Mean	Std
Linear frequency	4.22	1.31	3.56	1.54
MIDI note	3.56	1.15	3.33	1.24
Rhythmic loop	3.29	1.18	3.67	1.28
Ambient sound	3.78	1.11	3.06	1.43

As shown in figure 9, apart from the rhythmic mode, the upper quartile of each of the other modes is equal to the maximum rating of 5. This is also an indication that using sound to provide movement feedback is effective. Ratings for all four modes range from 'moderate' to 'excellent' and users are able to understand the sonic feedback easily.

The users' preference in sound aesthetic varies more significantly as shown in figure 10. This is also apparent in the subjects' comments. These pinpoint the fact that there is still room for improvement in terms of sound aesthetics.

Based on the interviews, not all participants responded positively to all four modes of the sonification, yet at least one mode is favoured by each participant either from a comprehensibility point of view or by preference. Listed below are summarised comments abstracted from the interviews about participants' experience of each mode. These comments have been re-worded into categories based on their meaning.

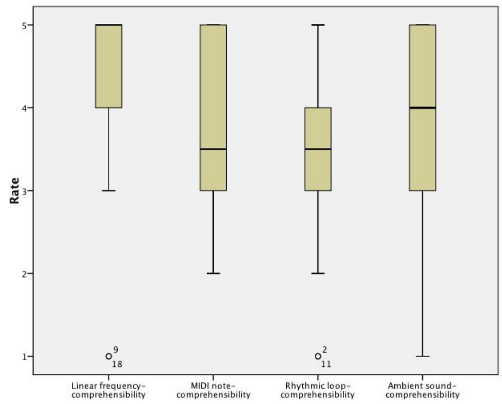

Figure 9: *Comprehensibility rating*

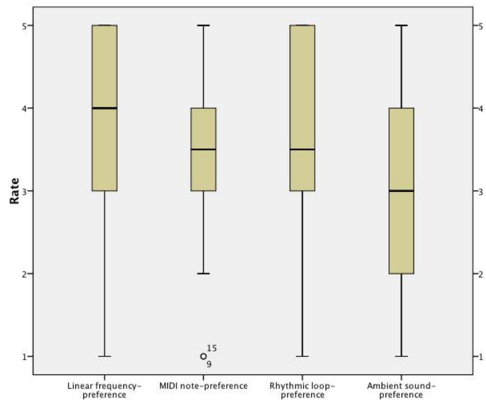

Figure 10: *Preference rating*

1. Linear Frequency Synthesis Sound Mode

> *"It is easy to understand and it functioned clearly; the dynamic representation is very clear."*
>
> *"You can listen to the change of the muscle and it is the most raw presentation."*
>
> *"The noise indication is really useful. In terms of the movement, specific motions are easy to repeat."*
>
> *"Aesthetically not good enough. The sound is noisy."*
>
> *"I like the sound because it is new to me. I slowed down more than I would usually do to prevent hearing the noise."*

Most participants (89%) agreed that this mode gave sufficient information reflecting their exercise. Yet their major concern is the unfamiliarity with the linear synthesis sound and aesthetic preference. 33% report that they did not enjoy listening to this type of sound because they do not regard it as a musical tone.

2. MIDI Note Synthesis Sound Mode

> *"I don't think it provides as good feedback as the frequency mode."*
>
> *"Faster notes seem to indicate worse exercise. But it also creates a big leap if I moved too fast. So I didn't enjoy it that much."*
>
> *"The sound was unrepeatable, so the feedback felt a little random."*
>
> *"This mode is the most interactive one. I needed to slow down my pace a lot to generate a clear melodic pattern. And the melody is different each time. But it didn't seem to inform me much about the dynamics of my movement."*
>
> *"It was difficult to understand."*

This mode was designed to split the movement range into 10 steps. However, generally, people without much training experience tend to do curls much faster than desired (less than 4 seconds per repetition). This results in a quicker MIDI note change, which leads to less clear melodic progression. One of the participants called it a 'big leap'. Hence, the preference for this mode is inversely related to the movement speed; people who moved slower enjoyed the sound more than people who moved quickly.

3. Rhythmic Sound Mode

> *"There is a progression I enjoyed listening to. But the loop starts again every time I finished one repetition. I would rather be able to hear the whole melody."*
>
> *"I didn't like it because I kept getting the wrong sound. It was distracting. It motivated me though to try to do it right because I hated the wrong sound though."*
>
> *"It is a good idea. But at the moment it doesn't help me too much. It would be better if the sound could be changed to my own mp3 files."*
>
> *"This one is very interesting. The exercise is periodic, just like most music. So I adjusted my pace to try and fit with the rhythm of the sound."*
>
> *"The sound was pleasant to listen to."*

This mode provides the most musical content compared to the other three. It is interesting that it became the most popular mode in the second session with an average preference rating of 4.0 and a standard deviation of 1.0. It transferred periodic movement into periodic music. Yet it has the problem of being too repetitive, and because of this a few participants suggested making the music selectable from their own music playlist.

4. Ambient Sound Mode

> *"It has the right balance between information and aesthetic. It was pleasant and natural."*
>
> *"Generally it is good but it is too relaxing and makes it harder for me to concentrate."*
>
> *"Comprehensible; the louder and more intense the sound means more muscle strength."*
>
> *"It is quite random." "I felt less control over the sound." "Not enough feedback."*
>
> *"It is special and immersive." "It is relatively easy to recognise."*

Currently this mode has the lowest ratings in preference from both sessions, and received the most negative comments (56% of negative opinions). Despite ranking second in mean comprehensibility for both test sessions, interviews still showed that people thought they had less control over the sound. Only one participant showed support for this mode. The positive response reflects the purpose of this mode for creating a relaxing sonic atmosphere. Yet having such a low popularity clearly indicates that this mode either requires a major improvement or faces removal in the planed future tests.

6.6. Discussion

The results from the pilot study indicate that a novel approach of providing real-time sonic feedback of biceps curl exercises can produce useful cues to the user and can influence the quality of the exercise. Comparing the results in dynamic range and repetition time between two sessions, we did not observe a significant result in the change of movement dynamic range. However, a significant increase in repetition time was achieved. Overall, subjectively, most participants found the device useful for maintaining a good pace of movement, and good for reducing the sensation of fatigue. Yet there are concerns over the listening experience, which is mainly due to personal preference of the sounds.

Our initial plan was to provide four types of sonification so that there were several choices to accommodate the issue of personal music preference. The rating of the questionnaire supports this concept as all participants have at least one preferred sound that they found both informative and enjoyable. However, further development of the sound design is essential to provide a better listening experience. It is also suggested that improvement is required of the sonification mapping for a clearer indication of the dynamics of the arm movement.

We believe that the sonification device has great potential to improve the quality of general exercise. However, due to the design of the pilot study, we focused more on the user experience in order to help us improve the system for a future test. This study did not include a control group to provide comparative statistical evidence to support the hypothesis. Therefore, a thorough hypothesis test will be conducted in the near future including both latitudinal and longitudinal experiments to compare the exercise results between a group of participants with the sonification feedback and a group without. In addition, the subsequent experiment will also study on the influence of fatigue and whether the sonification feedback has a positive or negative effect when user is feeling tired.

7. FURTHER WORK AND CONCLUSION

We are developing a game-based difficulty system that introduces a "hi-score" concept to motivate the user do to better each time they use the device. We aim to provide more tasks to further professionalise the user's movement through sonic feedback, and to further optimise the sound design.

In the subsequent hypothesis test, a latitudinal experiment and longitudinal experiment will be conducted. These two tests aim to discover and track the differences in exercising quality between participants who use the real-time sonification feedback and a control group who do the same exercise but without audio feedback. We will be looking into factors such as movement dynamic and velocity, repetition, EMG patterns, and subjective comments. Appropriate statistical methods such as student's T test and Pearson's chi-squared test will be used for comparative analytical purposes.

One of the possible extensions of the project to the area of **physiotherapy** is to use the sonification device in rehabilitation training. In this context sonified bio-feedback could be used to correct the patient's prescribed exercise. This has the potential of accelerating the recovery process from conditions such as strokes, which often requires a sustained level of rehabilitation exercises. Such a device could be used at home so that patients can receive feedback without the constant presence of a physiotherapist.

Another prospect is to migrate the sonification device to a **smartphone external device** or watch-based wearable computer with a suitable software application. This would offer better accessibility to users and allow more possibilities of getting feedback for outdoor exercise.

8. RESOURCES

The software and audio examples can be downloaded from the following link:

https://sites.google.com/a/york.ac.uk/jiajun/shared-files

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