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Catch Your Breath - Musical Biofeedback for Breathing Regulation

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ABSTRACT

Catch Your Breath is an interactive musical biofeedback system adapted from a project designed to reduce respiratory irregularity in patients undergoing 4D-CT scans for oncological diagnosis. The medical application system is currently implemented and undergoing assessment as a means to reduce motion-induced distortion in CT images. The same framework was implemented as an interactive art installation. The principle is simple - the subjects breathing motion is tracked via video camera using fiducial markers, and interpreted as a real-time variable tempo adjustment to a MIDI file. The subject adjusts breathing to synchronize with a separate accompaniment line. When the subjects breathing is regular and at the desired tempo, the audible result sounds synchronous and harmonious. The accompaniments tempo gradually decreases, which causes breathing to synchronize and slow down, thus increasing relaxation.

1. INTRODUCTION

Catch Your Breath is an effective example of the use of music for biofeedback. Applied biofeedback has been defined as:

> ...a group of therapeutic procedures that utilizes electronic or electromechanical instruments to accurately measure, process, and feedback to persons information with reinforcing properties about their neuromuscular and autonomic activity, both normal and abnormal in the form of analogue or binary, auditory and/ or visual feedback signals. Best achieved with a competent biofeedback professional, the objectives are to help persons develop greater awareness and voluntary control over their physiological processes that are otherwise outside awareness and/or under less voluntary control, by first controlling the external signal, and then with internal psychophysiological cues. [1]

Auditory biofeedback has been applied to a wide range of medical and health-related tasks including auditory occulomotor biofeedback [2], balance and gait control (e.g. [3, 4]), and athletic performance enhancement [5]. In addition to rehabilitative and assistive technologies auditory biofeedback has long been used in a variety of breathing control paradigms, primarily related to self-regulation [6] [7] and relaxation. At least one commercially available product (employing auditory biofeedback for breathing regulation exists [8]. Although the use of music for biofeedback has been suggested [9], typically, in these applications, the auditory feedback consists of single tones, or in the case of [8], individual musical chords. An obvious drawback is the difficulty in maintaining attention to a-contextual sounds, be they timbrally interesting or not.

In an effort to improve the efficacy of auditory biofeedback, particularly in situations that demand prolonged subject sessions, the use of adaptive interactive musical contexts for biofeedback stimuli was engaged.

Catch Your Breath originated as an application designed to meet the challenge of prolonged patient interaction in a medical imaging situation. Subsequently, the setup was decoupled from the hospital device and used as a single-user interactive music installation that has been successfully presented in museums, technology fairs and conferences.

2. MOTIVATION

The primary motivation for developing *Catch Your Breath* was the challenge of capturing useful data in 4D-CT scans in situations wherein patient motion, such as breathing irregularity causes significant signal perturbation. Our collaborators, Paul Keall from the department of Radiation Oncology at the Stanford University Medical Center and Siddharth Gopalan from the School of Engineering at Stanford, were thus designing audiovisual biofeedback hardware to be incorporated into a Four-dimensional computed tomography (4D-CT) scanner as a method to reduce motion-induced image distortion.

2.1. Purpose

4D-CT, an integral tool in diagnosing lung cancer, suffers from imaging artifacts that arise from irregular breathing. Patients who are undergoing oncological diagnosis are nervous and breathe irregularly. This poses the issue of significant noise in 4D-CT and MRI scans. By reducing the irregularity of breathing cycles, the imaging process gains a significant increase in efficacy. Prior to implementing musical stimuli a sinusoidal signal was used to provide auditory biofeedback. While somewhat effective, it was deemed difficult to maintain attention to the stimuli for prolonged duration and some subjects fell asleep during the trial (figure 1).

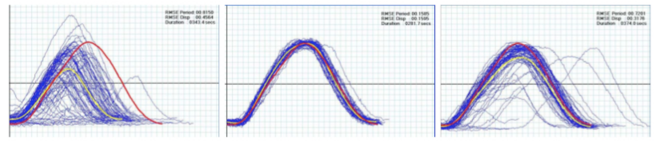

Fig. 1: Pilot subject results showing respiratory cycles overlaid on each other for (a) free breathing, (b) with feedback and (c) a volunteer sleeping during feedback. Free breathing shows a typical wide variation in respiration magnitude and period. Audio-visual biofeedback shows substantial improvement. However the system needs to engage the volunteer more to maintain concentration.

In the CT scanner prototype, the patient's breathing is monitored by a camera and a reflective cube to optically scan the motion of the chest cavity during the imaging process (figure 2). After determining the period of patient's ideal breathing rate, a musical accompaniment is selected with a tempo and harmonic rhythm to match the target breathing rate. A predetermined musical track consisting of the accompaniment pattern of a piece of music commences followed soon after by the principal voices of the music whose tempo is controlled in real-time by the tracked breathing pattern of the patient. The accompaniment and principal parts align harmoniously and in consonance when the patient's breath entrains to the target breathing pattern.

2.2. Efficacy

Initial tests show the auditory biofeedback for patients who undergo a 4-dimensional computed tomography (4D-CT) and magnetic resonance imaging (MRI) scans successfully provide a more predictable breathing rate and to calm the patients during these

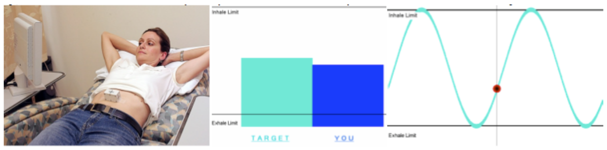

Fig. 2: (a) Picture of the current 4D-CT setup with reflective cube placed on patient. Two visual feedback displays implemented - (b) bar (patient tried to match target trace) and (c) wave (patient tries to trace the moving representative waveform).

lengthy scans. Initial results of the audio-visual feedback system shows a 55% reduction in respiratory variations and 70% decrease in period variations.

3. ARTISTIC APPLICATION

Preliminary 4D-CT subject trials suggested that simple two-part or homophonic music worked most effectively. Concurrently, the development team recognized the potential for creative interaction with more sophisticated musical textures and materials. A single-user interactive system decoupled from the imager was designed using inexpensive and robust technology such that the system could be effectively placed in a museum or gallery setting and run continuously.

To date, the installation has been placed in an art museum, conferences, and the fourth annual Maker Faire in California.

4. METHODS

The installation consists of a comfortable chair, a small pendant worn by the user, an inexpensive webcam type camera, a set of headphones and a portable computer.

The motion of the subject's breathing is tracked via webcam through the use of fiducial markers, and interpreted as a real-time variable tempo adjustment to a MIDI file. The subject can then adjust his/her breathing to synchronize with a separate accompaniment line. When the breathing is regular and is at the desired tempo, the audible result sounds synchronous and harmonious. The accompaniment's tempo progresses and gradually decrease which causes the breathing to synchronize and slow down, thus increasing relaxation.

4.1. Hardware

Catch Your Breath uses inexpensive, readily available materials. An early iteration of an installation version of this system used IR technology, similar to that of the medical school application. The IR sensor is then the only visible light, allowing for direct motion tracking from a single source. An IR LED mounted inside a pendant hung as a necklace around the user's neck. When worn by the subject, the casing naturally sits over the chest of the user with the sensor pointing directly at the camera. Tracking is performed along the X axis, as one inhales and exhales. A webcam, shielded by unexposed, developed slide film that serves as an ambient light filter, placed to the side of the user and would track the motion of the IR LED along the x-axis using Jitter. Max/MSP would then filter that data, detecting peaks and troughs. Each peak resets the trough to a default value, and vice versa, so that the full range of motion would be recorded. A button embedded in the pendant changes between training and mastery modes and cycles through a pre-stored library of music. The CT scan implementation is complemented by visual feedback. The museum installation is designed to work effectively with or without the visual feedback. Reliance upon auditory feedback alone seems to be equally effective as a means of self-regulation.

There was inconsistent data for the IR tracking, so the system was modified using fiducial marker tracking [10]. The open source software for the reacTable, called reacTivision, tracks predetermined fiducial markers. In this implementation, the fiducial markers are placed on a weighted pendant that is hung around the user's neck, resting on the chest or belly. As the user breathes, the marker moves and is picked up by a webcam, which tracks in reacTivision and sends data to Max/MSP using OpenSoundControl. Max/MSP then processes the data in a similar way as that of the IR tracking, detecting peaks and troughs.

4.2. Software

One MIDI file is the bass line, or leader, which is set at a constant tempo assessed during a training period. The other MIDI file is the melody line, or follower, which is constantly updated based on how fast or slow the user breathes. The two MIDI sequencers are synchronized using a millisecond clock that aligns when the two files are approximately the same tempo. When the user breathes in tempo with the leader, the music will synchronize.

Software was written in Max/MSP with Jitter. Jitter tracks the IR sensor. Max then calculates the peaks and troughs associated with a breathing cycle. The time between bangs of each peak and trough is then scaled as a beat per minute. The beat per minute is then exponentially scaled to a multiplier for MIDI files. Two MIDI sequencers, each with real-time tempo variability, are synchronized by a millisecond clock that aligns the time when a tempo is altered. In the visual feedback system, Jitter is used to create an animated visual representation of the leader and follower tempi using colored geometric objects that breathe along with the auditory feedback.

4.3. Implementation

The installation is set in a corner with a barstool facing a wall that is unadorned, except for a list of instructions. In the version with visual feedback, the barstool faces a flat screen plasma display. The user sits on the stool, dons the sensor pendant and presses a switch to enter a training mode, to change from training to mastery mode, to change the music, or to reset the system. The museum installation version sets the tempo of the leader at a pre-determined rate. In the 4D-CT scanner implementation, the tempo of the leader is computed during a preliminary observation period in which an averaged and normalized breathing rate is determined.

When the system starts, the music begins with one or more parts (often the chordal accompaniment, or bass-line) set at the leader, and the remaining parts (typically the melody) set at the follower tempo. By regulating breathing rate, the leader and follower can be made to synchronize with one another. Thus the sustained synchronization of all sounding parts of the music correspond with a desired regular rate of breathing.

5. CONCLUSION AND FUTURE WORK

The initial implementations of *Catch Your Breath* have proven effective in tracking respiration, identifying a normalized *target* breathing rate, and providing a feedback system within which the subject is provided real-time musical response to help regulate her breathing rate and periodicity to match the normalized target. In the artistic implementation, the system can be set to gradually alter the subject's breathing rate by progressive tempo adjustment.

In addition to continuing to investigate the impact of audiovisual biofeedback on 4D CT, the impact on 4D PET imaging, increasingly used for lung cancer radiotherapy has been added to the the medical development agenda.

We continue to fine-tune system responsiveness and expand upon the musical repertoire.

Beyond the medical and artistic applications. future work will include further study on efficacy of the system for controlled relaxation and to lower blood-pressure. We are currently designing implementation on ubiquitous portable devices.

Further implementations include training young musicians to practice detecting and staying with a given beat, including during accelerando and ritenuto, and also using this system as a compositional tool.

6. ACKNOWLEDGMENTS

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