HeartBeat: design and development of a headphone-mounted heart rate monitor

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INTRODUCTION
Overweight and obesity accounted for $51 to $78 billion in national costs in 1998 alone [1], over 60% of Americans are classified as either overweight or obese [1], and heart disease is still the primary cause of death in the US [2].

Good diet and exercise are the best methods for avoiding these health problems, but even though the average American watches over four hours of television per day according to a report by A.C. Nielsen Co., a 2006 Gallup poll found the average American only gets three hours of moderate exercise per week.

Heart rate monitors are used to provide a good measure of exercise intensity, which is important information for general exercise, athletic training, and rehabilitation. But these devices can be cumbersome, awkward, and make exercise less appealing. By augmenting a pair of headphones with a heart rate monitor, the wearer can listen to music while monitoring his/her heart rate simply and easily.

METHODS AND MATERIALS
A pair of Sony headphones was augmented with an infrared sensor. A receiver circuit (above) provides amplification and band pass filtering of the sensor signal. As shown at left, the frequency response of the filter has a peak gain at 2.3 Hz and the settling time is under 2.0 seconds.

A pair of headphones were augmented with an infrared light-based sensor, capable of measuring blood flow with photoplethysmography (PPG). An emitter and receiver were placed on opposite sides of the ear and the light absorbance was measured. Pulses in blood flow can then be observed, allowing heartbeatsto be identified.

Theoretical circuit characteristics

The receiver circuit (above) provides band-pass filtering and amplification of the sensor signal. As shown at left, the frequency response of the filter has a peak gain at 2.3 Hz and the settling time is under 2.0 seconds.

RESULTS
The final iteration of the device, circuit, and UI design yielded the elements shown below:

Theoretical circuit characteristics

FILTER

ECG signal before and after band pass filtering

Overlay of ECG, pulse oximeter, and HeartBeat signals, annotated with heartbeats.

User interface captures, filters, and analyzes the sensor signal and displays the current heart rate

accuracies (10-46) for the pulse oximeter and each headphone monitors by experiment and subject. Device failures (samples with accuracy < 50%) were censored from these datasets. Experiments were: control (1), general activity (2), running fingers (3), sit table reclined/level/inclined (4/5/6), holding breath (7), and after 5 minutes of vigorous exercise (8).

Pooled across all experiments, the accuracies for the right and left headphone monitors and the pulse oximeter were 86.7%±2.8, 86.3%±4.2, and 86.3%±4.7, respectively. From a series of paired t-tests and ANOVAs, it was found that the right headphone monitor was significantly more accurate than the left. There was no significant difference between the performance of the left headphone monitor and the pulse oximeter, implying the HeartBeat performed at least as well as the pulse oximeter. All devices were significantly affected by both experiment and subject, but the accuracy was not significantly correlated with the device. In addition, inclination and time did not significantly affect device accuracy.

CONCLUSIONS
A pair of headphones were augmented with infrared (IR) light-based heart rate monitors able to achieve accuracies of over 80% during general activity. These “HeartBeat” monitors were as accurate as an industry-standard pulse oximeter and tended to have a lower failure rate. By decoupling the emitter and receiver in the IR sensor, improved motion resistance was achieved. With further improvement of the device fit, receiver circuit, and digital processing, this device could provide reasonable accuracy during periods of exercise.

LITERATURE CITED

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FURTHER INFORMATION
Further information regarding this work, including the corresponding research thesis, PowerPoint presentation, and the digital version of this poster are available for download at http://students.washington.edu/stasis.