ABSTRACT
Visualizing graphs on mobile devices can be a tedious task for users, which requires them to use gestures to manually navigate through the plot, in addition to analyzing it to extract patterns or insights. In this paper, we discuss the development of an animated narrative of breathing data on mobile devices like the iPhone. The application offers users a visual summary of their breathing performance over a short period of time, where they are provided with insightful annotations while they monitor their levels of calm. Performance is measured on a subjective scale indicative of the level of Calm, and compared to a baseline that the users set in advance. The graph dynamically changes its color to reflect stress or calm moments, which is a physical metaphor meant to remind users of their breathing cycles.

Problem and Motivation
Providing individuals with means of better understanding one’s physiological system as well as providing tools to help improve one’s self-regulatory system is a vital step in improving and dealing with high stressors.

Current projects on breathing rate and awareness display our breathing through static visualizations such as graphs and charts [5]. On a mobile device like the iPhone, the size of the screen forces users to manually navigate through these static images to find interesting moments or patterns that they can draw insights from. This translates to using gestures like pinching to display more granularity, or panning to navigate forward or backward in time. This manual navigation is an overhead to users who want to get quick feedback on their performance during a day.

The complexity behind understanding our own breathing can become tedious when it requires investment of our time into understanding what is going on with our own bodies. Moreover, this complexity can create a barrier that prevents users from coming back to check their performance on the app, or checking it more regularly. Hence, making the “checking” behavior easier increases users’ ability to extract more value from the technology, and also makes them more likely to repeat the behavior. On the other hand, providing users with a reward when they check their progress can reinforce this behavior and thus increase their engagement with the application. In summary, the high-level challenge we faced was to find a way to make breathing performance visualization easier and more gratifying for mobile app users. More precisely, we tried answering the question of how to provide users with important
insights about their breathing behaviors without having them do the navigation or analysis themselves. Our goal was to passively communicate high-level insights to users in an engaging and fun way that would reward them for checking their performance. Rather than asking the user to focus on understanding the data, an animated visualization of breathing data annotated with contextual comments can inform non-experts with more insights about their breathing patterns and connect them to their daily activities. Through our novel visualization technique, we aid users by providing a dynamic means of understanding their own respiratory system that will emphasize breathing patterns as well as encourage users to induce calm through breathing awareness.

RELATED WORK

Calming Technology
The Calming Technology lab at Stanford directed by Neema Moraveji, has developed an iPhone app called Breathwear, which focuses on bringing calm by taking advantage of our daily use of mobile devices [2]. In particular, the app provides real-time breathing feedback to its users in order to encourage calm breathing and better physiological well-being. One particular form of developing or improving awareness of one's breathing patterns is through the Breathwear notifications, which alerts a user about their breathing dynamics.

Static Data Visualization
Other mobile device applications have been developed to display breathing data with the use of respiratory sensors. Various breathing sensors are in the market that synchronize with mobile devices to provide real time data on various physiological characteristics, including breathing patterns. We identified issues with prior products in that often times, users need to understand what breathing data is or looks like before beginning to understand and improve upon oneself through these mobile applications. Often times, the data could be overwhelming such that large and seemingly random amounts of data is displayed and up for self-interpretation.

One method used by companies such as MyCalmBeat is through an information dashboard [6]. Information dashboards provide real time or real life data and display it through static visualizations such as in Figure 3 by presenting breathing rates numbers in chart form. These visualizations are effective in efficiently presenting data but often times do not display it intuitively or in ways that require users to self-interpret the data at hand. In particular, looking at the numbers on a chart requires users to understand what a typical breathing rate is and/or that higher breathing rates can be related to higher levels of stress or stress environments. We also examined other apps such as Breathe2Relax which provides breathing results through a line graph, providing individualized ceiling and floor functions to indicate "stressed" and "calm" physiological states [1]. In particular, this visualization focuses on stress management and attempts to provide insight on the effects of stress on the body.
However, our intent with developing a mobile visualization of breathing data is to provide an interactive and stylistic display of breathing information to promote self-awareness as well as encourage users to analyze and improve one's own physiological state. Not only do we want to bring awareness to the users of how breathing is affected by stresses and their environment, we also want users to be able to contextualize their own breathing data in an interesting manner that does not require background knowledge.

METHODS

Gathering Data
Data was provided by the Breathwear project of multiple users who wore breathing sensors over various days of the week. The data provided the start time of when the sensor was initialized and caught multiple data points over time until the breathing sensor was either removed or the application stopped recording data. Typically, users would run the breathing sensor over short sessions (~40-60 minutes) multiple times through the day. The particular data we were given included a timestamp (recording the date and initial start time), the number of seconds elapsed since the initial start of the recording session, breathing rate, and a stretch value. It is also important to note that there was an initial start delay before the sensor would begin reporting breathing data of about 80 seconds.

Data Processing
Figure 5 shows a plot of raw breathing rate data (breaths per minute) over a random session. The data is very choppy, as can be seen from the overlapping thick blue lines. In order to reduce that jitter, we down-sampled the data by a factor of 10, then ran the new data through a fourth-order low-pass filter. With the filtered data, we used Bezier curve interpolation to draw a smoother graph like the one in Figure 6.

Figure 5. Raw breathing data

Animated Plot
As a way of engaging users with their breathing data and providing high-level feedback without requiring their direct manipulation, we implemented an animated rendering of the breathing rate graph, as shown in Figure 7, which shows the animation in progress. In addition, as a way of providing insights, we determined important spots to pause at in the graph, and we slowed down the rendering rate at these specific locations, to highlight their importance. Finally, we wanted users to be able to instantly localize calm regions and feel rewarded at their sight, so we colored the surface under the breathing graph in blue, mapping higher color intensity to higher levels of calm, as shown in Figure 8.
Figure 7. Animated graph implementation

Axis
One goal we had with our application is to allow users to understand their data without the expectation that they have a medical background or knowledge on breathing rates or patterns. With this in mind, we revised the y-axis of our graph to contain 3 levels: “stress”, “zen”, and “calm.” We determined these three states through Breathwear and Moraveji’s previous research [5]. Using these three levels and a baseline, users can view when their breathing rates rise above the “zen” zone into what Moraveji determines as “high stress” breathing patterns.

Baseline
We provided the “zen” zone as a point of reference for users by mapping it to a pre-determined baseline breathing rate from Moraveji’s research and user studies [5]. The baseline is user-specific, not global, and can be calibrated to the user’s breathing patterns, or alternatively set by the user as a personal goal.

Color Feedback
In addition to the qualitative y-axis, we provide a color mapping to allow the user to quickly assess his or her performance at the current point in time in the playback. We decided on the redundant encoding to both make the animation more engaging, and to lessen the burden on the user when interpreting the graph. Figure 8 shows the color-encoding, with a very calm period signified by the calming blue color of the plot.

Paused Annotations
We chose interesting breathing data points such as extremely “calm” zones or high “stress” zones and decided to emphasize these points to the users. We provide static annotations as shown in Figure 8, while also pausing the animation to really emphasize these data points. In particular, our annotations are to help bring awareness of particular data points where users are doing particularly well or could improve upon their breathing. When users are in high stress levels, rather than providing negative commentary, we provide suggestions or questions to encourage users to think about why their breathing rate is higher at this particular point in time. We attempt to provide positive feedback and helpful questions to encourage improvement, reward success, and help the user better understand their breathing patterns.

Figure 8. Color feedback and paused annotations

Implementation

Frontend
We built an iOS device application with Objective C using various frameworks and libraries such as CorePlot, QuartzCore, and sqlite3.0 to graph our data.

Challenges
One issue we came across when dealing with the data we were given by the Calming Technology lab is that the time points over which the sensor recorded data was discontinuous. Rather, the sensor would gather short “spurts” of data. Because our graph would display continuous amounts of time (ie. 1 hour or from 10:30 am - 10:30 pm) but not all seconds within this time period would have data, we had to figure out a way to display this lack of data. At first, we thought about discontinuous plotting, jumping ahead in time to the next available data, but we realized this would be confusing to the user, who would not understand why there was a jump in time or completely misunderstand that data was missing. Therefore, our approach was to graph zero breathing rates where data was missing.

RESULTS
Currently, the dataset is pre-loaded from prior collected data because breathing sensors could not be provided immediately for our users to test. Users who
better interacted with our visualization tended to be more familiar with iPhones and iPhone applications such that they understand the ability and feature of panning, zooming, and scrolling.

Overall, we received positive feedback at our demo. In general, people were very interested in the topic and wanted to learn more about tracking their breathing with an application. Constant feedback we received was in relation to the many different use cases with our plug-in to Breathwear. In particular, we were brought to awareness of multiple possible user groups that would benefit from our application. A main use case we had not anticipated addresses medical conditions and healthcare providers. Through the use of Brythm, patients and their healthcare providers can monitor breathing-related conditions such as sleep apnea. Patients, who are most likely non-experts, can easily view their breathing data without needing a doctor or healthcare provider’s explanation of the meaning behind the breathing data on screen.

We also received technical feedback that would be very valuable to incorporate in future iterations of our prototype. One of the challenges our real users faced was the ability to make sense of the time periods on the x-axis of the graph which were displayed in seconds. We quickly realized it was more intuitive to plot time in increments of hours. Another valuable piece of feedback was inverting the y-axis metric so that a calmer state would map to a higher y-value instead of a lower y-value. We also received many suggestions for new featured that we will share in the Future work section.

**DISCUSSION**

Through the process, we developed multiple prototypes that shaped and attacked various goals we were attempting to achieve through our visualization. Intuitively, we wanted to present a physical and visual metaphor for a user's breathing pattern. The goal achieved providing a stimulating visualization that was interesting as well as informative. Through an animated pulsation, we wanted to create a visualization that would show a user through comparison and contrast the various changes in breathing rate over time. One issue we came across with this prototype is that the pulsation was not a direct translation of breathing rate but instead a normalization to fit the animated time span we had set. In addition, when users viewed the pulsations, they began to breathe in sync with the pulsation, an effect we did not want.

Our second approach was to present data through a narrative visualization. Through this, we wanted to present the data as a story and more specifically to non-experts. We attempted to minimize the clutter of our animation while balancing this with providing enough information for users to leave the visualization with new knowledge about their breathing patterns. In our project demo, users appreciated animation of the graph, stating that the live feedback was "similar to reliving our day." Interestingly, users remarked that breathing is such a normal habit that viewing the dynamics and changes in their breathing rates definitely made them feel "more aware" of not only their breathing rate but also the changes in breathing patterns.

Our main challenge was attempting to balance providing just enough information while encouraging users to change behavior in a positive manner. Through our initial prototype, we changed behavior in that users were beginning to change their breathing merely by watching the pulsations. In our second prototype, users were able to interact with the actual data while also being able to "sit back" and re-watch their data in a stimulating manner.

**FUTURE WORK**

**User Annotation**

Future work on the graph may include allowing users to annotate the graph with notes or location or time specifics. Feedback we received during the demo included that users may know specifically why one point in the day deviations in breathing rate occurred and would like to note it for future reference. Users may want to "pin" the graph, which would allow users to have insight in patterns of their data where particular events or environments might create high stressor or high physiological or emotional involvement. In addition, pulling in calendar data as a form of annotation might help users where notes about particular peaks in breathing rate have been inputted from a schedule can give them quick insight without forcing users to recall exactly what they were doing at a specific moment in time during the day.

**Calendar and GeoLocation Data**

In the future, we would like to fetch calendar and geolocation data and display this dynamically on the plot along with or replacing the static annotations we currently use. In particular, with unique points of breathing data, we want to be able to provide analysis for the users, potentially displaying what they were doing at a particular data point (either positive or negative). Through this, we wish to help users become
aware of patterns in their breathing such as which events during the day seem to bring them to “higher stress” states or “better calm” states. This can also be applicable to geolocation.

History
An important feature that we received suggestions for future implementation is the ability to view multiple data sets or time periods at the same time. In particular, if a user wanted to be able to see why Tuesdays felt particularly stressful, he or she should be able to pull up multiple data sets from various Tuesdays and compare their breathing patterns to see if particular events or classes may increase breathing rate. In addition, comparing data is an important feature for future work in that it allows users to receive physical feedback on whether their promotion of respiration awareness and physiological state has an effect.

Personalization
Some personalization would be helpful for users. In particular, if users want to see a longer time interval or control the length of the animation, future features could include the ability to speed up or slow time the speed at which the animated graph is displayed. Users may also want to (as noted in feedback) personalize the colors or the thickness of the line of the graph. These small UI changes can dynamically improve the user experience, though we chose to focus mainly on implementation details for this iteration.

New Sensor
The current Breathwear sensor does not record actions such as sighing, laughing, and talking. However, the newest prototype has been recorded to accurately catch these actions and record breathing data. With this new data, an interesting feature to be implemented would be to feature these actions as annotations as we plot the data. Users can gain a new sense of what actions can be associated with unique breathing patterns.

CONCLUSION
We were very thrilled to be contributing to the Breathwear project, and helping people be more aware of their breathing behaviors. The question of displaying graphical data on mobile devices was a very interesting challenge, and we think we have provided a fresh perspective that can be iterated on in the future. We strongly believe that an interactive data visualization to help individuals better understand their own physiological system and breathing can not only help bring self-awareness of one’s own physiological state but also boost users’ engagement with the tracking technology by encouraging them to use it more regularly to track their breathing.

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REFERENCES