Evaluation and Comparison of Usability of Four Mobile Breathing Training Visualizations

ABSTRACT
Breathing exercises are an accessible way to manage stress and many mental illness symptoms. Traditionally, learning breathing exercises involved in-person guidance or audio recordings. The shift to mobile devices has led to a new way of learning and engaging in breathing exercises as seen in the rise of multiple mobile applications with different breathing representations. However, limited work has been done to investigate the effectiveness of these visual representations in supporting breathing pace as measured by synchronization. We utilized a within-subjects study to evaluate four common breathing visuals to understand which is most effective in providing breathing exercise guidance. Through controlled lab studies and interviews, we identified two representations with clear advantages over the others. In addition, we found that auditory guidance was not preferred by all users. We identify potential usability issues with the representations and suggest design guidelines for future development of app-supported breathing training.

Author Keywords
Breathing exercises; mental health; wellness; usability

CCS Concepts
+Human-centered computing → Human computer interaction (HCI); Usability testing; Please use the 2012 Classifiers and see this link to embed them in the text: https://dl.acm.org/ccs/ccs_flat.cfm

INTRODUCTION
Mental health is an important public issue. In any given year, around 20% of the adult population in the United States suffers from mental illness [25]. The cost of mental illness is high, associated with an 8.2-year average decrease in lifespan [12] and accounting for $139.2 billion in lost income each year in the United States [18].

Breath training has been shown to reduce stress [4], improve athletic performance [15], and improve mental health symptoms [33, 4, 7]. Traditional breathing training methods are presented in the context of stress reduction, symptom relief, or overall physical wellness and include a diverse set of schools including diaphragmatic breathing, deep breathing, Buteyko breathing, yogic breathing, tai-chi, and qigong. Each type of breathing practice is beneficial for solving specific types of problems although there are some overlaps in the benefits of each technique especially in the realm of stress reduction. Pursed-lips breathing [24] and diaphragmatic breathing, for instance, have been shown to improve breathing patterns in people with Chronic Obstructive Pulmonary Disease thus improving airflow [37]. Relaxation-breathing has also been shown to reduce anxiety in children [5] while the Buteyko breathing technique could improve symptoms of asthma [8]. Yogic breathing, or Pranayama, has been demonstrated to improve competitive swimmers’ respiratory function and endurance [15]. Qigong breathing has been shown to have a beneficial effect on stress levels [20].

Traditionally, breath training has been taught by a professional or using audio recordings. This limits the accessibility of such information for low-income populations (who also have greater rates of mental illness) [22] in the former case and for deaf and hard of hearing individuals in the latter case. Recently, however, this gap has been bridged by using technology such as biofeedback and mobile applications. Biofeedback has been used to give participants real-time and visual responses to their biological signals [36]. This has extended to utilizing smartphones for biofeedback [10].

Breathing exercises have also been introduced in mobile apps in the larger context of wellness apps and mindfulness, rather than by itself. Many commercial applications exist for teaching breath training either as a primary or a secondary feature. Meditation and mindfulness apps make up a significant amount of the apps that provide breath training as a secondary feature. One such app is called Stop, Breathe, & Think [29]. Users check the app periodically, look inwardly to assess their feelings, and input their physical, mental, and emotional status in order to be aware of their present state. The app then suggests possible activities the user can do to improve awareness of the present moment, one of which is a breathing exercise which can be done using pre-recorded audio guidance or a self-guided customizable session. After users complete the mindfulness activities, they check in again and update their status if it has changed during the session. Since Stop, Breath,
& Think [29] and other apps such as Headspace [17] introduce the breath as a means of being aware of the self’s present state to increase mindfulness in everyday life, such apps tend to contain fewer customization or settings for breathing training although they may track the frequency of use and visualize usage patterns.

Other smartphone apps are focused solely on deep breathing and offer differing forms of breath training, such as relaxation and yogic breath training. As such, they require a way to communicate the proper breathing technique. These applications contain different visualization methods for the breath, with four methods being the most popular.

In this paper, we use the terms representation and visualization interchangeably to refer to methods of conveying the breathing exercises. The underlying breathing technique may be the same but it can be presented in various ways according to the app designer. Chittaro and Sioni [6], in their evaluation of two types of breathing representations, provided an overview of several different types of breathing visualizations. They have coined terms describing the four most common representations as described below.

The first visualization is wave-based, which shows a continuous straight or curved sine-based wave to guide the user’s breathing cycle. An example of one such application is Paced Breathing [21], shown in Figure 1. The wave can be moving through a stationary line, or the wave itself can be stationary and the line is moving through it horizontally or vertically.

The second visualization is sphere-based. This is arguably the simplest representation which involves a circle (or sphere) expanding and shrinking according to the breathing phase. Figure 2 shows a simple sphere-based representation from The Breathing App [34]. Sphere-based representations can be more elaborate. The shape is more complex but the underlying idea is the same, that is, to breathe in accordance with the change in size of the image. Breathing Zone [35] is an example of an app that utilizes this more complex representation.

The third visualization is cylinder-based. It shows a cylinder being filled to the top during the inhale phase and emptying in the exhale phase. Breathe2Relax [30] is an example of such an app. Figure 3 shows a mockup of such a representation.

The fourth visualization is a donut chart. It is typically segmented into three or four sections, with each section representing a breathing phase. The user can see their breathing progress through the cycle and phase, almost like a progress bar. Prana Breath [1] is an example as shown in Figure 4. Variations include a pie chart instead of a donut chart. There are also hybrid varieties, for an example, a sphere inside a donut chart such as in the Stop, Breathe, and Think app [29].

There are other types of visualizations beyond those covered in Chittaro and Sioni’s work. One example is found in the Headspace app [17] where there is a rotating square containing the circle, shown in Figure 5. As the square completes a quarter of a revolution, the circle drops onto another edge of the square, signifying the start of a new breathing phase. In this case there is no unique signifier of which phase the user is supposed to breathe in. Other representations include following the movement of a butterfly or other animal as it flits through the space of a screen [31].
Apps such as Paced Breathing [21] and Prana Breath [1] allow Apple Watch [16]. This app shows an expanding and contracting shape in which the user is supposed to breathe according to its movement and is an example of a more complex sphere representation. The app also provides habit tracking and customization features. Apps such as Paced Breathing [21] and Prana Breath [1] allow users to choose what type of audio feedback they would like to hear, if any, to signal the changes in the phase of breath during the subsequent sessions after the initial session. Most apps utilize only one method of visualization, and some will allow the user to customize speed settings and tactile and audio feedback with or without a fee. While several methods exist, there is no indication as to which representation is the most effective in facilitating paced breathing exercises, thus we set out to investigate which methods are best for breath training.

Our research questions are as follows:

- Are some representations better than others in facilitating paced breathing exercises? We measure “better” using subjective user evaluation and breathing synchronization accuracy. We want to investigate user satisfaction with the current representations of the breath and the breathing cycle. We are especially interested in how users compare them to each other, since many app users will download and try more than one app. We particularly want to evaluate the accuracy of each representation when it comes to breathing synchronization.

- How can visualization of breathing practices be optimized for greater effectiveness? The measures of effectiveness in this situation can vary, from reducing stress to mitigating symptoms of mental illness, to lowering blood pressure. We focus here on breathing synchronization with the assumption that if properly done, breath training will lead to its other associated improvements such as decreasing stress levels and lower blood pressure. In particular, we want to examine the strengths and weaknesses of each visualization and determine some design criteria or guidelines for future applications.

- How does audio guidance impact the user experience in learning and performing the breathing exercise? A previous question was raised whether the visual element of breathing exercises would be helpful or distracting to people who wanted to perform breathing exercises. Chittaro and Sioni [6] concluded that this visual component was not distracting to users. We want to extend this question further to the auditory realm and determine how audio feedback and guidance impacted users’ experience in interacting with these apps.

**RELATED WORK**

To date, breath training tools have fallen primarily under the commercial application domain with many smartphone and smartwatch apps in circulation. These apps utilize various forms of visualizations for communicating breath synchronization, but to our knowledge, there is little research that indicates which are the most effective. Previous attempts to render human breathing have been explored in the realm of computer graphics. Zordan et al. designed a model of an anatomically-accurate human torso and simulated the breathing using a model of a pair of human lungs [38] in order to model a human breathing pattern. Tsoli, Mahmood, and Black showed realistic human breathing but modeled it within 3-D models [32]. While both works do not directly reference breathing exercises, their models can potentially be used to facilitate paced or deep breathing exercises. Auditory guidance has been previously used to facilitate paced breathing. For instance, Gavish evaluated device-guided breathing with audio in the form of musical tones to help patients with hypertension, and found that the paced breathing exercises were effective in reducing physical symptoms. In this case, the musical tones helped the patients to emphasize the exhalation phase over the inhalation phase [14].

Dijk and Weffers developed an immersive system called Breath with the Ocean, which utilizes visual (light-based) stimuli, audio guidance, and haptic feedback with the goal of relaxation [9]. However, they found problems with users not being able to adjust to the breathing exercises when they were...
Within the frame of mobile-based breathing applications, there was integrated into the seat of a simulated car and utilizes to determine which method of representing breathing exercises found in the Apple App Store. We conducted a survey of the different versions of visualization with the breathing app and to observe their responses to each design.

Evaluations of Visualizations
Within the frame of mobile-based breathing applications, there has only been one study conducted that evaluated the effectiveness of each representation. Chittaro and Sioni [6] compared audio-only guidance with the sphere-based representation and the wave-based representation to determine which one is more effective utilizing a within-subjects approach. They defined effectiveness using the change in physiological signs associated with relaxation as well as a subjective evaluation using a questionnaire. They found that the wave-based representation is significantly more effective both physiologically and subjectively than the audio-only instructions. However, they did not find that the sphere-based representation performed better than the audio-only instructions. While Chittaro and Sioni’s study investigated stress reduction to some degree, we are interested in better understanding why some representations outperformed others, focusing on the users’ ability to synchronize their breathing and their reactions to audio feedback.

STUDY
To determine which method of representing breathing exercises is the most usable, we designed and implemented a user study with N=24 participants to measure their level of synchronization with the breathing app and to observe their responses to each design.

Survey of Mobile Applications
In order to determine which representations to focus on, we conducted a survey of the different versions of visual representations of breathing exercises found in the Apple App Store and the Google Play Store. Search keys included terms such as deep breathing, breathing exercises, breathing techniques, and breath training. We excluded virtual reality applications, voice-only applications, exact duplicates, sensor-only applications, and timer-only applications.
Table 2. The four representations we developed for testing. We extracted the basic components of the four most common representations and simplified them. Here, each row corresponds to a different kind of representation. From top row to bottom row: donut chart, cylinder, sphere, and wave. The columns contain the four phases of the breathing cycle. From the leftmost to the rightmost column: inhale, hold, exhale, and hold.

track the breathing phase changes. We utilized cameras as it has been shown that this relatively low-cost and unintrusive method performs comparably well to respiration belts [23]. One camera was set up to capture a similar range as that described by Nam et al. [23], recording the participants’ chest and torso movements as shown in Figure 6. The two cameras were synchronized using the hand clap technique, which uses the sound of a hand clap as a landmark for lining up the two audiovisual feeds. We also interviewed participants after the study to gain information about their experience in using the app.

Participants
We recruited 24 participants from the [removed for anonymous review] and the surrounding community. Participants consisted of university students, staff, and community members. The participants’ occupations ranged from student to data entry to retiree, and their ages ranged from 19 years old to 74 years old. The mean age of the participants was 35 years, the median age was 26 years, and the standard deviation was 15.4 years. There was an equal set of male participants (N=12) and female (N=12) participants, with one self-disclosed bi-gender female participant (who requested to be counted as female). We included a broader population set to gather a large variety of users and determine the usage needs of a larger population, rather than a specific population or one that is more comfortable with using mobile apps.

We selected participants who were not familiar with or did not have much experience with using mobile apps for breathing, relaxation, or mindfulness training, since participants who are accustomed to a certain method of visualization employed by their application of choice could be biased towards the one that they use regularly. However, we did not control for whether
participants had previous experience with guided breathing that was not supported by technology. Prior to the study, participants were not informed of the defined purpose of the representations beyond the fact that the representations were supposed to facilitate breathing exercises. Thus, participants were not able to judge each representation based on its ability to meet its purpose of guiding breathing pace.

Procedure
Before the session, each participant filled out an informed consent form. At the beginning of the session, the experimenter described the study procedure. Then the experimenter applied two stickers on the participant’s chest and torso (shown in Figure 6) to track the breathing movements. The experimenter showed the main screen of the application and gave the subject a randomized sequence of exercises to perform. Participants were asked to not interrupt the exercises but rather ask questions before or after each exercise.

Each of the four exercises had eight breathing phases over 2 cycles and lasted 30 seconds. We chose 30 seconds as the base length of each exercise because our goal was to explore the usability of each design rather than its efficacy in reducing physical stress signals and having each participant complete an entire session of exercises for each representation was not necessary.

The experimenter provided as little verbal information as needed to not influence the participant’s impression of each representation. Participants had to perform the exercises without any preconceptions as to how each representation worked.

After the exercises were completed, the experimenter interviewed the participant about their experience using the app, any difficulties they had, and their overall opinion of each visualization method. Participants were given a $5 gift card as compensation. The list below shows the interview questions.

- Which representation was your least favorite? Why?
- How insecure, discouraged, irritated, stressed, or annoyed were you?
- Which representation did you find to be the most easy to use? Why?
- Which ones did you find hard to use? Why?
- Please rank the representations in order of which one you liked most to least.
- How did you like hearing the tone versus complete silence?
- What is your gender?
- What is your age?

ANALYSIS
Here, we utilized open coding to qualitatively analyze the interview data. To obtain the breathing synchronization results, we measured the difference between the participants’ breathing and what was displayed on the screen and used confidence intervals and simple effect sizes to report our results.

Qualitative Analysis
After we completed the interviews, we transcribed them and used open coding to identify salient themes that emerged. By briefly going over the interview transcripts we identified areas of interest and generated a codebook. Two members of our team went through and coded four interviews independently. It was determined that a sufficient level of agreement was reached at 71%, and one team member coded the rest of the interviews independently.

Breathing Synchronization Quantification
We took the data from the two videos and compared the participants’ breathing to the guidance provided in the visualizations. The two cameras recorded the video in 29.97-60 frames per second. We were able to synchronize the two recordings up to the frame. Our sampling was determined by frames per second used by each camera, and phase changes were marked down to the frame by noting the directional change in movement of the marker on both stickers. We used Lightworks, a video editing software, to synchronize and mark the breathing phase changes in both the visual representation and the participant’s breathing.

Instead of using p-values, we utilize confidence intervals and simple effect sizes to report our results [11, 13] rather than standardized effect sizes because of their robustness [2]. In this case, simple effect sizes refer to raw mean differences and have the same units (seconds) as the data. Although we interviewed 24 participants, due to complications when gathering the data, we were only able to collect 22 data points for the cylinder and sphere and 23 data points for the wave and donut chart.

RESULTS
Based on an analysis of the data, two representations, the wave and the donut chart, outperform the sphere and the cylinder in terms of breathing synchronization. However, the wave was the least favored while the donut chart was the most favored among users.
Breathing Synchronization

Figure 7 shows the average time difference between each breathing phase change and the participant’s breathing itself. The cylinder and sphere performed poorly compared with the other two representations, with 1.04 ± 0.22 seconds and 1.11 ± 0.26 seconds delay for visual only and 1.13 ± 0.17 seconds and 1.02 ± 0.38 seconds delay for audio guidance included. The wave-based and donut chart and wave representations had the lowest and best reaction times with 0.31 ± 0.24 seconds and 0.40 ± 0.38 seconds delay respectively for visual only and 0.30 ± 0.32 and 0.35 ± 0.23 seconds delay for audio guidance.

These reaction times are average and the error bars in the figure indicate a 95% confidence interval. In many cases, the participants started the phase change earlier than the guidance indicated, and this resulted in a negative value for the time delay.

User Feedback

We also asked participants to rank which representations they liked most to least and to identify the easiest and hardest representation(s) to use.

The rankings of the most to least preferred representations are shown in Figure 8. The donut chart was ranked the highest the most often, with twelve participants ranking it as their first choice and five ranking it as their second choice. Only one participant ranked it as their last choice. In contrast, the wave-based visualization was the least favored out of all four. Sixteen out of 24 participants ranked it as their least favorite, with only two ranking it as their favorite. The cylinder is the second most popular, with five ranking it as their favorite and another ten saying it was their second favorite. The donut chart and cylinder representations were ranked as the least favorite only once for each.

Qualitative Themes

The rest of this section discusses the common themes we found through user interviews. These themes translate into design implications for developers.

The wave-based representation was the most confusing. Eleven users said that they had issues with the wave-based representation. They were confused by the motion of the wave and some expressed that they felt there was a lack of guidance compared with the others. P8 elaborated, "It was totally confusing especially when it came without sound...When it came without sound, I didn’t know what to do. I thought the wave coming up is inhaling and the wave going down was exhaling but then after that I was no no no, not yet and it was confusing." In contrast, six of the participants commented that they found the donut chart to be clear and intuitive.
Users prefer predictability. Seventeen of the 24 subjects commented on how predictable the exercises were. The most common complaints against the sphere and cylinder visualizations were that the user cannot predict when the breathing phases will change. These participants are most often the ones who favor the donut chart the most. Interestingly, although the wave-based visualization provides a level of predictability, many users who commented on it did so negatively, such as P15, who said “I felt like it’s one of those things you see moving back and forth and I kept going too early or too late or just not hitting the mark at all.” Only two of the seven users who remarked on the wave’s predictability did so positively, saying that they could see what was happening next. Some users only like a certain level of predictability. P7 wanted to see the entire cycle: “I want to see the complete exercise. The whole cycle in the sense of like the whole interface.” However, commenting on the donut chart, P18 said that she did not like it as much as the wave because the donut chart was “thinking too far ahead.”

Users are split over auditory guidance. Ten users liked the tone because it helped them focus on the exercise and bring their attention back to the current phase when their minds had wandered. Others said that it made certain representations easier or more palatable. For example, P10 appreciated that, “It really helped with [the wave] to have the tone so I didn’t have to be watching the line. I imagine if I were familiar with the app and I wanted to close my eyes and practice these exercises in a meditative state the tone would be very helpful.” The other fourteen disliked it for two reasons. Five of them said that they would have preferred a different tone and nine said that they preferred complete silence. The five who preferred a different tone said that they preferred a softer, “smoother” tone such as nature sounds or differently-pitched tones to communicate the current phase, such as a higher sound for the inhale phase and a lower sound for the exhale phase. Three users said the tone was distracting because of the sound itself, while four users found the tone helpful in keeping their focus. Even when they looked at the visualization they found themselves becoming distracted. P5 explained, “At times I did not actually focus on the screen and there was a moment where I actually lost focus so the sound helped me stay in focus.”

The same exercises mean different things to different users. Twelve of the fourteen users had twelve different interpretations of the exercises, with the cylinder and wave being most common exercises being interpreted. For the cylinder exercise, the various interpretations are container/glass of water (6), lungs (3), breathing machine (1), and progress bar (1). For the wave, the interpretations are string (1), sine function (1), and a “flat line in a medical facility” (1). The donut chart was interpreted as a progress bar (2) and a timer (1). The sphere was the least interpreted, with one user interpreting it as “simulating machine breathing.” One user viewed the same exercise two different ways, seeing the cylinder as both a glass filling up and their lungs filling up.

Some users related the representations to their bodies. Seven users related eleven exercises to their body movement or indicated that they disliked that they could not relate it to their bodies. The wave-based representation was the least relatable. P9 said, “That is just a line that goes up and down. It’s not really relatable for me.” P19 remarked, “I don’t think breathing really works that way...your shoulders do not raise up as you inhale.” In contrast, the cylinder and sphere representations were the most related, with five and four instances respectively. Users said that the expansion of the sphere and the filling of the cylinder reflected their lungs expanding in their bodies.

Length is subjective and dependent on user perception of the representations. Five participants felt that certain representations were longer or shorter than others despite the identical phase length duration. Their perceptions differed among all four representations. P13, for example, sensed that the wave took longer than the sphere while P18 remarked that the wave “had the best timing.” P14 and P18 felt that the donut chart exercise was too short. P10 commented that the cylinder took too long, “beyond my comfort level of holding.” This perception of length also differs within exercises as well, with P18 also feeling that the cylinder had a “relatively long inhale and exhale and a relatively short hold period.” Some participants acknowledged that the phase duration was probably the same for all the exercises but they still perceived some as longer than others. Also related to length is the power or force of the air being breathed in and out. P6 liked the wave-based representation the best because he knew how powerful he should inhale or exhale. He did not like the cylinder because he could not get that information from it.

Informal Study
After examining the results, we realized that the study raised more questions about the effectiveness of the cylinder and sphere representations. Our implementation of the sphere and cylinder were non-linear in their movement. That is, the sphere did not change in size at a constant rate. Rather, it expanded/contracted faster at the beginning of the inhale and exhale phases and slower as it reached the end of the phase. The cylinder also filled and emptied faster at the beginning of the inhale and exhale phases and slowed down as it approached the end of the phase. We implemented the representations in this way since it was the way they were presented in the apps available in the market. Thus, we wondered whether the non-linear movements of these representations reduce their breathing synchronization rates. These movements may have caused the participants to misjudge the length of each phase, and presenting these representations with a linear movement may increase the synchronization rate.

Thus, we recruited five participants for an informal study with these two representations presented linearly without auditory guidance and a donut chart presented without auditory guidance as well for reference. We analyzed the data in the same way as described previously. Our results (shown in Figure 10) did not indicate that removing the nonlinear aspect of the sphere and cylinder visualizations increased the users’ breathing synchronization. The means for linear sphere and cylinders were $1.27 \pm 0.31$ seconds and $0.94 \pm 0.27$ seconds, respectively. The donut chart had a $0.19 \pm 0.41$ seconds delay.
DISCUSSION

Breathing Synchronization

It is interesting to note that while adding an auditory component resulted in reduced reaction times for the donut chart and the wave-based representations, it did the opposite for the sphere and cylinder. It is noteworthy that the sphere and cylinder do not provide visual cues of when the phases would change, while the donut chart and wave do. While the wave sample means indicate that users perform better than the donut chart, the error bars overlap so that it could be that the wave and donut chart have similar performances or that the donut chart outperforms the wave. Thus, given the intervals that the means can lie on in the 95% confidence interval, we cannot authoritatively state that the wave-based representation outperforms the donut chart.

However, what we can say given the confidence intervals is that the wave and donut chart both perform better than the cylinder and sphere since their confidence intervals do not overlap. This is likely due to their predictability. This correlates with users’ feedback that they could see when the phases change when performing the exercises with the wave and donut chart but not with the cylinder and sphere.

Breathing Guidance Beyond Visualization

While users’ views of the auditory guidance was mixed, there is still room for investigating further methods of teaching breathing exercises without relying on visualizations alone. For instance, further exploring how auditory guidance could be modified to improve user opinion, it would be useful to evaluate user reactions to different tones. Since study participants suggested using sounds from nature (such as ocean waves) or musical tones, it warrants an investigation on the roles that these sounds would play in the user experience overall.

Haptics is a broad field that has applications for teaching breathing exercises. As discussed in the related works section, there has been previous work done in utilizing haptics alone and in conjunction with other feedback types for facilitating paced breathing. Paredes and Chan, for instance, found that haptics by itself is useful for guiding deep breathing exercises and that pressure-based haptic feedback could be better than vibration-based feedback.

Dijk and Weffers found, like we did, that many users tended to prefer to close their eyes. They also theorized that multiple forms of feedback can be overwhelming, since they found that their users who focused on all three forms of feedback, visual, audio, and haptic, spent much effort concentrating and thus could not relax as much as other users. Therefore, care should be taken so that if haptic feedback were introduced, it would either be optional or would be unobtrusive. Both audio and haptic feedback can be integrated into a mobile app and users should be able to choose what kind of feedback they desire and customize the combination, intensity, or type of feedback they receive.

Design Suggestions

Because the wave-based visualization is as effective or more effective as the donut chart, and because some users prefer it to the other visualizations, making this exercise more palatable to users is beneficial. In redesigning this representation, we still want to preserve its predictability and perhaps even increase it as that was a benefit many users noted. The main complaint against this design was that it was confusing. This can be alleviated by adding colors that correspond to the current phase. Adding markers to signify phase changes as shown in
Figure 11 (such as a dot that appears at the intersection of the moving and stationary line or an outline around the sphere) could also improve clarity. In doing so, the effectiveness of the exercise is preserved while at the same time potentially increasing its usability.

For the sphere-based visualization, sometimes users had to tap the representation a few times before they could begin the exercise. Often, the start of the exercise caught them off guard. Adding a countdown before each visualization begins will help users feel more prepared to begin the exercise and synchronize their breathing better with the guidance.

The cylinder exercise was the second most popular representation out of the four. It was also the most interpretable and relatable to the body’s movement. Users did not synchronize to this exercise as well as the donut chart and wave representations because of its lack of predictability. To preserve the interpretability and relatability of this exercise but to add predictability, designers can add a counter indicating how much time is left in a certain phase as shown in Figure 12. While this probably would not make users synchronize as well as the other exercises (due to the fact that there is still a margin of one second assuming the counter is counting down by the second), it will improve the predictability of this exercise. Adding color to mark the phases would not improve the exercise, as it could make it less interpretable and it is unnecessary as the position and movement (or lack thereof) of the liquid filling the cylinder will indicate what phase the exercise is in currently.

Because users can favor a representation for the same reason another user might dislike it, adding more than one visualization option would be helpful. If designers were to include two visualizations, we suggest that they choose the donut chart and the wave representations. The donut chart is the most predictable and the most popular, and the wave can easily be improved to make it more appealing to users without sacrificing its performance. While the cylinder representation is more relatable and more favored than the sphere, it does not prove accurate enough to warrant including it in apps. The cylinder, while more popular than the wave, still needs to be more accurate and thus should not be used in its current form.

Other issues that designers can address include differentiating between deep and paced or slow breathing. Some participants commented that they felt like a certain exercise helped them breathe in more deeply than others. This could be due to the speed of the movement in a phase (e.g., the speed of the cylinder filling up or slowing down) or the linear versus non-linear progression within a phase (e.g., the donut chart has a linear progression in a phase because the progress bar moves steadily but the cylinder fills and empties at a non-linear rate). In this study we chose to utilize non-linear progression in the cylinder and sphere representations because it was the most commonly used method in the market. There are also apps with non-linear progression of the wave such as the Breathe app [19] but they are not as common. Since the human lung takes in air non-linearly [3], the non-linear expansion of the sphere and the non-linear filling of the cylinder may be a more natural movement and thus more interpretable. However, it could make it harder for users to follow even if they feel it corresponds better with their body movement.

This was what motivated our informal study discussed in the previous section. Our results do not suggest, however, that the linear representations perform better than the non-linear representations. In fact, the linear sphere had a higher mean at 1.27 seconds compared to its nonlinear version at 1.04 seconds although the confidence intervals overlap. The linear cylinder had 0.94 seconds breathing delay, which may be better than the nonlinear cylinder at 1.11 seconds with similar but overlapping confidence intervals. Given the 95% confidence intervals, we can state that the donut chart still has an advantage over the linear sphere since its highest possible mean is still lower.
than the linear sphere’s the lowest possible mean. It may perform similarly to the linear cylinder, whose lowest possible mean is 0.60 which is equivalent to the donut chart. Thus, from our limited informal study we cannot state that making the exercises linear will improve breathing synchronization. There are advantages and disadvantages to both approaches. Making the movement in a phase non-linear speed could help users know how deeply they can breathe, while keeping this movement steady will help users know how quickly or slowly they are expected to breathe.

Limitations
Because the exercises were performed on a tablet, like most touchscreen/portable devices the tablet vibrates whenever it plays audio. While this is not caused by a vibration actuator but by the sound the device emits, it a source of haptic feedback and may affect the results of the audio portion of the experiment.

Our quantitative analysis was limited by our sample size. Because we had 23 data points for the wave and donut chart representations and 22 data points for the sphere and cylinder representations, our confidence intervals were relatively large and we could not determine whether the wave or donut chart performed better, only that these two performed better than the cylinder and sphere representations.

CONCLUSION AND FUTURE WORK
Our findings correlate with previous study findings that wave-based visualizations outperform sphere-based visualizations. However, since users reacted the most negatively to the wave-based visualization, designers should improve this representation to increase user satisfaction while maintaining its effectiveness. Application developers who utilize current visualizations should focus on the donut chart and wave representations rather than the sphere (which is currently the most popular representation on the market) or cylinder. Since users reacted the most negatively to the wave-based visualization, designers should improve this representation to increase user satisfaction while maintaining its effectiveness before using it. From our findings, the work remains to design and test a new representation combining the best features of the four that we tested. This design could integrate the best features of each representation into one single exercise.

In the future, we plan to explore whether different visualizations are more effective for certain populations or for ameliorating certain issues. Because other forms of breath training such as yogic breathing in the form of sectional breathing, alternate nostril breathing, and bellows breathing are effective in improving sports performance [15], we need to investigate whether different representations of different schools of breath training (such as Buteyko or yogic breathing) will work similarly to paced breathing.

Some users preferred to keep their eyes closed during the exercises, thus another avenue for future work would be to integrate haptic feedback in the form of vibrations and see how this affects the effectiveness and usability of the exercises. This can be done in conjunction with auditory guidance and separate from it. Testing the exercises using wearable devices such as smartwatches can help determine if solely haptic feedback is useful for the population that prefers to keep their eyes closed. In addition, haptic visualizations such as those described in [26] would be useful to pursue to ensure that guided breathing exercises are suitable for those with vision impairments.

ACKNOWLEDGMENTS
We are grateful to [anonymous] for assistance in coding the results. We would also like to thank our participants who gave us their time and effort to contribute to this project.

REFERENCES


