BrightBeat: Effortlessly Influencing Breathing for Cultivating Calmness and Focus

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Abstract
While technology is usually associated with causing stress, technology also has the potential to bring about calm. In particular, breathing usually speeds up with higher stress, but it can be slowed through a manipulation, and in so doing, it can help the person lower their stress and improve their focus. This paper introduces BrightBeat, a set of seamless visual and auditory interventions that look like respiratory biofeedback, rhythmically oscillating, but that are tuned to appear with a slower speed, with the aim of slowing a stressed computer user's breathing and, consequently, bringing a sense of focus and calmness. These interventions were designed to run easily on commonplace personal electronic devices and to not require any focused attention in order to be effective. We have run a randomized placebo-controlled trial and examined both objective and subjective measures of impact with N=32 users undergoing work tasks. BrightBeat significantly influenced slower breathing, had a lasting effect, improved self-reported calmness and focus, and was highly preferred for future use.

Author Keywords
BrightBeat; intervention; breathing; GBR; MBR.

ACM Classification Keywords
H.5.m [Information interfaces and presentation (e.g., HCI)]: Miscellaneous

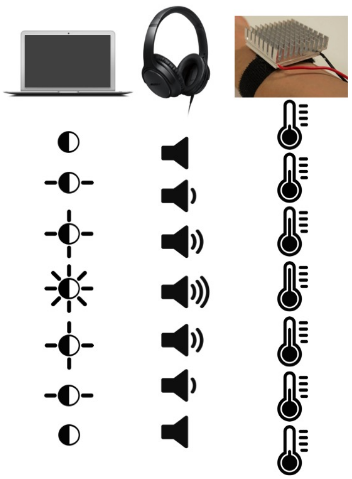

Figure 1: Schematics of BrightBeat systems: oscillating visual, auditory, and thermal feedback. The thermal feedback has been used in earlier user studies with the system. We focus on visual and auditory components in this paper.

Introduction

Scientific evidence confirms that the relationship between breathing and regulatory effects is bidirectional. Stress [1] has physiological indicators including changes in core temperature, cardiovascular tone, respiratory patterns, and more [11]. Among these, respiration has a unique characteristic of being both voluntarily and involuntarily controlled. Also, voluntary deep and slow breathing can induce physiological, affective, and cognitive calm [16].

In this era when individuals spend hours in front of screens, wearing headphones or other wearable devices, technology can be a promising medium for delivering seamless calming interventions throughout everyday life activities. However, little research has been conducted around conveying a portion of the positive influences of a meditative experience *while* being involved in daily activities. Also, most technology designed for improving wellbeing requires deliberate attention rather than utilizing automatic mental processes for behavior change. Adams et al. refer to the latter concept as mindless computing [7]. Thus, BrightBeat ironically uses mindless computing techniques to promote a respiratory-induced mindful state in everyday activities.

This paper explains the design and implementation of BrightBeat and its validation through a structured user study. BrightBeat is a set of interventions in the form of subtle changes in the screen brightness, headphone volume, and a custom wristband's temperature that oscillate with a calming frequency. The frequency is personalized to the user's relaxed state to respect individual differences. The "beating" appears (visually, auditorially, or through warmth on the skin) just-in-time to influence slower breathing. BrightBeat lies on the boundary between subliminal and superluminal stimuli. It is noticed mostly only by a user who has become distracted and defocused. Also, the subtle changes that BrightBeat presents are not likely to be noticed by anybody else, thus helping preserve the privacy of the user's affective state. Fig. 1 schematically illustrates BrightBeat.

To measure objective effects on breathing, the user's physiology is monitored via a Zephyr BioHarness sensor. Our findings show that BrightBeat users develop slower relative breathing rates, are able to achieve their goal breathing rate a higher percentage of the time, and report higher focus and calmness levels. BrightBeat users indicate that it is barely perceptible (i.e. does not significantly increase self-reported system awareness) and not distracting (i.e. does not influence performance significantly).

Related work

Breathing and calmness

Studies have confirmed that breath modification can influence changes in the affective state [26]. Deep and slow breathing has been widely used as part of relaxation techniques in patient populations to treat somatic disorders such as hypertension and pulmonary diseases [14], psychiatric disorders including anxiety and depression syndromes [9], post-traumatic and other stress-related disorders [24]. Not only in patient populations, but also in healthy individuals the physical and psychological effects of deep breathing have been shown. For example, it improves cardiovascular health [27], mental function and attentiveness [31], wellbeing, mood, and stress tolerance [10].

Breathing and technology

McCraty is among the pioneers of scientifically using biofeedback for improving wellness through training, education,

[1] Stress can refer to a spectrum ranging from negative (distress) to positive (eustress) [stimulation] [29]. In this paper, we are only focusing on stress as negative, and on reduction of breathing frequency to assist in calm, but also BrightBeat can be used to speed up breathing, to help a person become more activated.

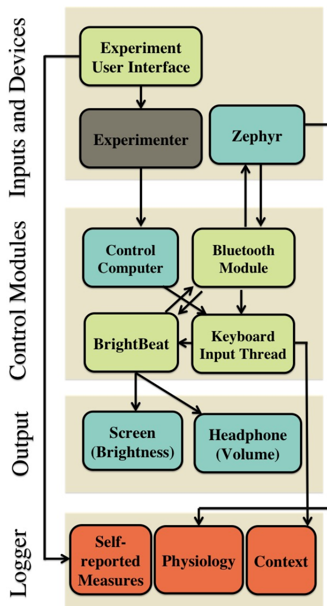

Figure 2: System design. Color codes: blue: hardware module, green: software module, orange: data, grey: experimenter.

and self-monitoring [21]. Other researchers have studied guided breathing using real-time rhythmic tones for reducing blood pressure and treatment of hypertension [13].

Moraveji has conducted a set of studies in this area [23]; he developed Breathbelt, and introduced peripheral paced respiration for visual pacing in parallel to information work by a bouncing bar on the desktop screen [22]. He implemented Breathaware, a gamified drop-down menu in the system tray for informing users about their breathing. Moravji later created Spire [6], a wearable tracker that measures breathing and encourages overall mindfulness.

Researchers have explored new ways for biofeedback breath training. Examples include utilizing games (e.g. [32], [8], [20], [25]), virtual environments (e.g. [30, 15]), and responsive physical environments (e.g. [33], [28]).

While there are a number of mobile applications that have paid overt attention to breathing (e.g. [3], [2]), many of them have not been scientifically validated. Also, they are based on full engagement of the user with a breathing exercise; which means that they are not designed as background apps that can coexist with another attentional task.

Physiological synchrony

Physiological synchrony and emotional contagion are known phenomena [17]. Levenson and Ruef provided several examples when autonomic nervous systems synchronize such as between patients and therapists, students and teachers, dyads and groups, mother and infant, spouses, and even in viewing oneself on videotape [19]. These examples show that the synchronization does not require face-to-face interaction, but can also happen across physical (in videotape) or interpersonal (between strangers) distance. This motivates further exploring the role of technology in this mirroring process.

What is missing?

To the best of our knowledge, most of the calming technologies that measure and influence breathing are designed to require full attention of the user and are not designed to work while the user is engaged in everyday life activities. A recent study showed that providing a false vibrotactile feedback of slow heart rate could reduce anxiety [12]. Building on these results and the evidence from physiological synchrony, we propose to design an intervention that influences calmer breathing by recreating a calming breathing signal.

Method

System design

The BrightBeat system captures breathing and determines an individualized breathing goal for each user. Fig. 2 depicts the system design.

To capture breathing, we utilized a Zephyr BioHarness [1] and used pyzephyr [5] to connect to it via bluetooth. Based on the literature on personalized breathing goals (e.g. [23]), the system monitored users during an approximately three-minute relaxation period and captured mean breathing rate (MBR). Then, it set a goal breathing rate (GBR) for each participant. Breathing rate during cognitive tasks is naturally faster than during a relaxed state; thus, to account for the individual differences in breathing habits, we set the initial value of GBR as $GBR = 120\% * MBR$. During a parameter setting section, users could adjust their GBR within $[MBR, 140\% * MBR]$. However, most users continued with the initial GBR value.

Whenever the user was breathing faster than his/her GBR, BrightBeat would appear. The visual component had three input arguments, minimum brightness (minB), maximum brightness (maxB), and GBR. The computer screen brightness would “beat" with GBR frequency. Each “beat” started

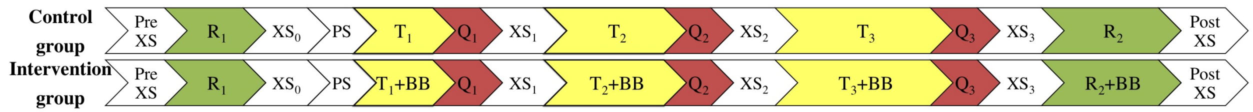

Figure 3: Experiment design. Pre XS: Initial survey and experience sampling. R1: Relaxation. $T_{1..3}$: Reading tasks. $Q_{1..3}$: Quizzes. $XS_{0..3}$: Experience sampling. R_2: Relaxation while reading. Post XS: exit survey and experience sampling. PS: Parameter setting. BB: BrightBeat.

from minB, went up linearly to maxB, and returned to minB again with GBR frequency. Also, the auditory component would play white noise in the background and adjust the system volume. Similarly, the audio module would “beat" linearly from minV to maxV with GBR frequency, sounding like an ocean wave. The initial system values were: $minB = 0.85, maxB = 1.00, minV = 0.0001, maxB = 0.5, GBR = 120\% * MBR$.

Experiment design and deployment

N=32 participants (13 males) including 8 undergraduate, 13 graduate, and 11 staff members of the university were recruited. Participants were randomized into control (13) and intervention (19) groups. The study protocol was reviewed and approved by the MIT Committee on the Use of Humans as Experimental Subjects (COUHES). The experiment (Fig. 3) was conducted in a lab setting and lasted between 40 to 50 minutes. It was composed of relaxation sessions, reading tasks, and quizzes. The experimenter was blind to the condition and only interacted with the participants before the reading tasks and after the session was over, to avoid affecting their breathing response. The control group was not exposed to BrightBeat. The intervention group was exposed to BrightBeat during reading tasks and the final relaxation but not during the quizzes.

Before starting, participants received instructions and signed consent forms. Participants were told that the goal was to focus on the reading tasks and answer quizzes correctly.

Both groups were told that BrightBeat would appear in a barely perceptible way when they were breathing faster than their goal. The control group was additionally told that BrightBeat's changes were so subtle that they could not be perceived consciously like in subliminal imagery; this was to keep them from stopping and asking if the system was working. To elicit stress, which is associated with faster and irregular breathing patterns, participants were told that their quiz performance would be compared to others.

Participants started with a relaxation session. They watched a short video about meditation followed by a guided breathing exercise. The MBR was calculated during this period. Then, they interacted with the system and confirmed its parameters. Afterwards, they were given three sets of reading tasks followed by quizzes. The tasks differed in length and difficulty. The participants were strictly timed and the form would automatically proceed to the next page after the time limit. Finally, they were told to relax while reading an article. They were informed that there was no quiz after this final task, so hopefully they could truly relax. In the end, they filled out a survey and rated their experience with the system. Self-reported calmness, focus, and emotional valence were captured pre- and post-study and after each task.

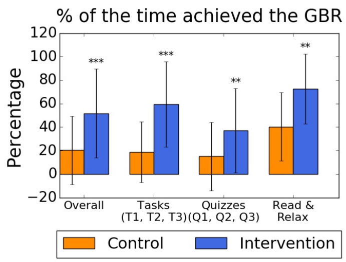

Figure 5: Average percentage of the time users achieved the GBR in each task with one standard deviation error bars. The intervention group has significantly achieved its GBR more than the control group during all types of tasks. Overall: overall except baseline, T: reading tasks, Q: quizzes, R2: relaxing and reading. $^{**}: p < 0.01, ^{***}: p < 0.001$.

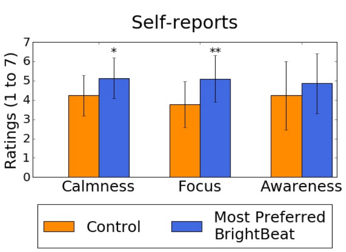

Figure 6: Average self-reported ratings for most preferred BrightBeat (visual or auditory) with one standard deviation error bars. Awareness: 1: not aware, 7: very aware. Calmness: 1: very stressed, 7: very calm. Focus: 1: very distracted, 7: very focused.

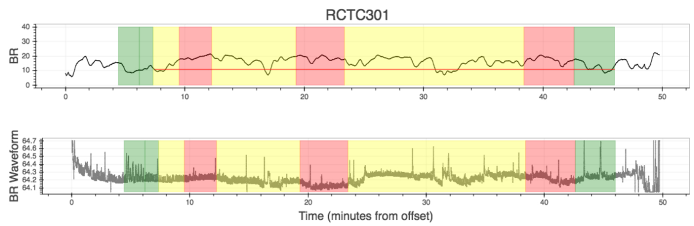

Figure 4: A sample control user. The red horizontal line is GBR (10 BPM). Green: Relaxation, Yellow: Reading, Red: Quiz.

Results

Physiological data analysis

Figures 4 and 7 show an example user in the control and intervention group respectively. The control user is mostly breathing faster than her GBR and only occasionally slowing down by taking deep breaths or sighing. However, the intervention user is usually below his GBR and sometimes going up during the quizzes where BrightBeat has been off. However, both users have healthy breathing rate variability.

For an overall comparison between groups, we calculated the % of the time that the GBR was achieved during each task for each participant and averaged all participants in each group for each task (Fig. 5). We used t-test with Bonferroni correction with adjusted p value threshold of 0.013. The intervention group significantly reached their GBR more compared to the control group during reading tasks [2], quizzes [3], the final relaxation session [4], and overall [5].

[2] $T_{intr}(M = 59.26, SD = 36.34), T_{cntr}(M = 18.81, SD = 25.93); t(30) = 5.92, p = 0.000$.
[3] $Q_{intr}(M = 37.25, SD = 35.81), Q_{cntr}(M = 15.15, SD = 29.09); t(30) = 3.17, p = 0.002$.
[4] $R2_{intr}(M = 72.56, SD = 29.93), R2_{cntr}(M = 40.40, SD = 29.23); t(30) = 2.92, p = 0.006$.
[5] $all_{intr}(M = 51.73, SD = 37.68), all_{cntr}(M = 20.32, SD = 29.03); t(30) = 6.67, p = 0.000$.

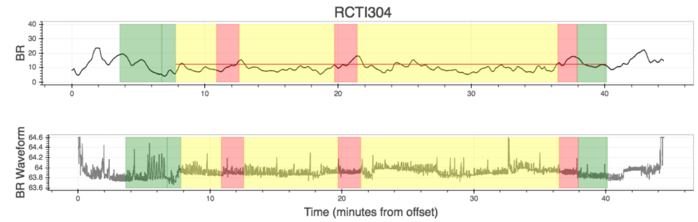

Figure 7: A sample intervention user. The red horizontal line is GBR (11 BPM). Green: Relaxation, Yellow: Reading, Red: Quiz.

Self-reported data analysis

There are individual differences among users' BrightBeat preferences (Fig. 8). Overall, 10.5% of the participants favored the visual component while 47.7% favored the auditory component. The remaining 42.1% rated both components the same. To account for these individual differences, we considered only the ratings from the most preferred component for each user in the intervention group. We detected univariate and multivariate outliers by using a box-plot and calculating the Mahalanobis distance respectively. Two users were removed as outliers [6]. Then, we applied a t-test for each self-reported measure. We used Bonferroni correction and considered an adjusted p value of 0.017. BrightBeat users were significantly more calm [7] and focused [8] compared to the control users. Their awareness of BrightBeat was not significantly higher than their control counterparts [9] which confirms that BrightBeat is barely perceptible. Fig. 6 shows the summary of the user ratings

[6] This improved the significance of the self-reported findings slightly while not affecting the other findings in any significant way.
[7] $calmness_{intr}(M = 5.14, SD = 1.06), calmness_{cntr}(M = 4.23, SD = 1.09); t(28) = 2.54, p = 0.015$.
[8] $focus_{intr}(M = 5.10, SD = 1.24), focus_{cntr}(M = 3.77, SD = 1.24); t(28) = 3.24, p = 0.002$.
[9] $awareness_{intr}(M = 4.86, SD = 1.56), awareness_{cntr}(M = 4.23, SD = 1.83); t(28) = 1.14, p = 0.260$.

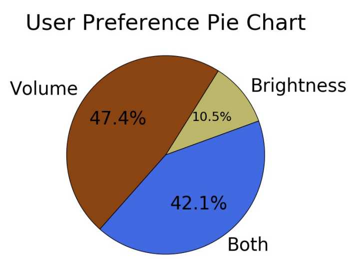

Figure 8: User preference pie chart.

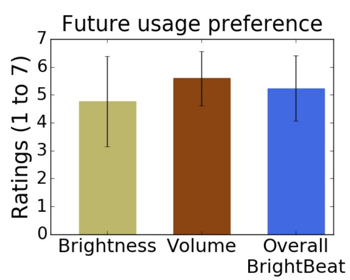

Figure 9: Average preference for future usage of the brightness module, volume module, and overall BrightBeat. Error bars show one standard deviation. 1: Not at all, 7: very much. Ratings of 4 or higher are positive.

of awareness, calmness, and focus in a bar chart with one standard deviation error bars. On average, participants said they preferred to use BrightBeat in the future (Fig. 9).

Performance analysis
Is it possible that BrightBeat was not as subtle as we wished, and that it distracted people and hurt their performance? We calculated the overall quiz results (%) for each user. However, no significant difference was observed between the control and intervention groups [10]. This shows that BrightBeat did not negatively impact performance.

User feedback
Our goal was to simulate a stressful task and analyze the effectiveness of BrightBeat in that context. Users' comments confirmed the stressful nature of the task in different ways (e.g. "The content of the articles was difficult to digest in such a short time without prior knowledge."; "The timed reading and tests made me more stressed out."; "Very stressful!"; "the fixed time limit stressed me out."). However, there were interesting insights about how different components of BrightBeat could help improve focus. Specially, users mentioned that it mostly helped them regain focus when they were distracted (e.g. "The subtle changes were helpful at keeping my focus. [...] Every time my eyes started to feel tired, the screen would noticeably brighten and that helped me immensely. I would appreciate the use of this during the work day, but especially times when I'm feeling distracted."; "I was only aware of subtle changes on the screen a couple of times, I think I became more aware of it the more distracted I was.").

[10] $perf_{intr}(M = 38.89, SD = 13.31), perf_{cntr}(M = 39.77, SD = 13.53); t(30) = -0.17, p = 0.87.$

Conclusions and Future Work
We have reported the design, implementation, and evaluation of a new set of intervention tools, BrightBeat. We narrowed the focus to two BrightBeat tools: a subtle modulation of screen brightness, and a subtle modulation of headphone volume. We have evaluated BrightBeat in a randomized placebo-controlled trial (N=32).

We showed that BrightBeat was calming: the intervention group had significantly lower relative breathing rates and reached their goal breathing rate more than the control group; they also reported higher calmness. BrightBeat was barely perceptible and not distracting: there was no significant difference between the system awareness of the control and intervention users; quiz performance of BrightBeat users was not affected; they also reported higher focus rather than feeling distracted from their primary task.

BrightBeat is a successful behavior change intervention that does not require constant attention. These findings suggest promising possibilities for future research on effortless health/wellbeing behavior change. As apps such as f.lux [4] adjust the screen's blue light emission to influence circadian rhythm, BrightBeat add-on can adjust the system brightness or volume to bring about calm.

For future work, we would like to improve the scalability by substituting the sensor with a non-contact measurement technique (e.g. [18]) and evaluate it beyond the lab environment. We would like to include more variables from the breathing pattern (e.g. inter-breath intervals, inhalation to exhalation ratio). We would also like to explore creating calming music based on respiratory variables.

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