Peripheral Paced Respiration: Influencing User Physiology during Information Work

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ABSTRACT
We present the design and evaluation of a technique for influencing user respiration by integrating respiration-pacing methods into the desktop operating system in a peripheral manner. *Peripheral paced respiration* differs from prior techniques in that it does not require the user's full attention. We conducted a within-subjects study to evaluate the efficacy of peripheral paced respiration, as compared to no feedback, in an ecologically valid environment. Participant respiration decreased significantly in the pacing condition. Upon further analysis, we attribute this difference to a significant decrease in breath rate while the intermittent pacing feedback is active, rather than a persistent change in respiratory pattern. The results have implications for researchers in physiological computing, biofeedback designers, and human-computer interaction researchers concerned with user stress and affect.

ACM Classification: H5.2 [Information interfaces and presentation]: User Interfaces. - Graphical user interfaces.

General terms: Design.

Keywords: Respiration, peripheral, biofeedback, stress.

MOTIVATION
Voluntary breath regulation is a common, empirically validated technique for reducing stress and anxiety [3, 10, 19], relieving symptoms of asthma [4], reducing blood pressure [5, 16], and focusing the mind for optimal performance [9]. Conversely, patterns in respiration reveal information about one's psychological state [9]; changes in breath may result from frustration, pain, stress, test anxiety [8], and post-traumatic stress disorder (PTSD) [22].

Schliefer and Ley [17] investigated the effect of computer data entry compared to baseline relaxed periods. They found that breath rate increased 26% during data entry and that subjects exhibited decreased heart rate variability (HRV) and increased self-ratings of tension. The differences were comparable to those linking threats of electric shock or anxiety of students before an exam with differences in respiration [17].

For our purposes, the most salient finding from studies investigating breath regulation is that reducing (some claim simply regulating [10, 21]) breath rate activates the parasympathetic nervous system (PNS), the so-called 'rest-and-digest' response, to relax the body, reducing stress and anxiety.

To date, technology-mediated respiration pacing has required the user to stop their current task and focus their full attention on the pacing. However, humans can "regulate their respiration rates in a relatively short time period" [22], making breath regulation a viable treatment for sporadic and subtle stressors such as those that may be encountered during the frequent task switching of information work.

We investigate methods of integrating respiration-pacing techniques into the desktop computing environment to enable *peripheral paced respiration* (PPR). Such a system would allow users to engage in other tasks while regulating breath, increasing its accessibility and frequency. To that end, this paper makes two contributions. The first is a peripheral visual feedback technique to influence respiration of a desktop user. The second is the results of a study evaluating the effects of PPR compared to a control condition lacking visual feedback.

RELATED WORK
Practitioners use various methods to entrain or pace respiration that fall generally into two categories: (1) consciously controlling their respiration or (2) entraining the breath to an external stimulus such as a visual animation [7, 19], a light in binary states for inhalation and exhalation [7], ambient lighting [21], or metronome [16]. In the second category, the choice of stimulus can lead to ambiguity about the length of each inhalation and exhalation. Methods with binary states (*e.g.*, when will the light turn off?) or brightness (*e.g.*, what is maximal brightness?) do not clearly indicate the end point of the current inhalation or exhalation.

Some end-user tools have emerged that aim to complement voluntary breath regulation. Resperate [16] uses auditory tones to guide relaxed breathing to reduce blood pressure. MyBreath [11] infers respiratory pattern from microphone input as the user breathes into their mobile phone. Pra-

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nayama [14] guides the user's breath during meditation with both visual animation of a pie chart being filled alongside auditory tones for inhalation and exhalation.

Existing respiration-pacing tools are *modal*: they require the focused attention of the user. Given the demonstrated ease with which users can entrain their breath to visual stimuli, we propose using short but frequent pacing sessions that are *peripheral*, allowing the user to engage in other tasks while concurrently pacing their respiration.

Breath rate (breaths per min, or bpm) is calculated by the number of times the chest rises (inhalations) in a minute. Breath rate, like heart rate, changes frequently even in a resting state [9]. It is affected by arousal, talking, posture, personal health, and other factors. There is no standard resting human breath rate; studies have found it to be between 12-20bpm for adults [9, 18]. There are different perspectives on what an optimal target breath rate should be. Song and Lehrer found a general optimal range of 4-6bpm is correlated with the greatest HRV and that HRV generally increases as breath rate decreases [20]. Stark, *et al*. showed that a target rate too different from one's resting breath rate requires greater attention and effort [21].

Peripheral pacing requires continuous monitoring and a medium for intermittent biofeedback. Only recently has the technology has become available to do continuous ambulatory monitoring (cf. Picard *et al*. [12]). To our knowledge, the work here is the first instance of peripheral respiration pacing being integrated directly into the desktop.

Picard and her colleagues describe *affective computing* as "computing that relates to, arises from, or deliberately influences emotion or other affective phenomena" [12]. Work in this genre attempts to create technology that adapts to, measures, or communicates the user's affective state [15]. Complementing this approach, our research attempts to influence the physiological factors underlying affective response.

A PERIPHERAL PACED RESPIRATION INTERFACE

Our design goal was to evaluate the feasibility of peripherally regulating the respiration of a desktop computer user. Such a system requires two functions: (1) sensing user respiration and (2) feedback to pace the respiration across computing tasks.

Respiration Sensor

There are a number of possible techniques for sensing user respiration (a review is available in [1]). Beyond methods enumerated in that review, researchers have used features extracted from video of a user's face, with [1] or without [13] thermal cameras.

As our focus is on pacing respiration, not non-invasive sensor design, we chose to build a sensor using off-the-shelf components. We measure changes in thoracic circumference, a robust and straightforward measure of respiration for healthy individuals (*i.e.*, those without apnea or obstructed airways) who are not moving a great deal. We use a single strap to sense breath rate. Such a sensor could be built into clothing or undergarments and does not require direct contact with the skin.

Our sensor (shown in Figure 1) uses a standard 2" cylindrical strain gauge attached to a canvas belt whose length can be adjusted with a common clip. The strain gauge works by changing resistance when stretched. Each end of the sensor is connected to an Arduino *Uno*, which in turn is connected to the computer using USB. The sampling frequency is 20Hz (50ms) plus a small variable error from reading serial data (~2ms), making it near-real-time.

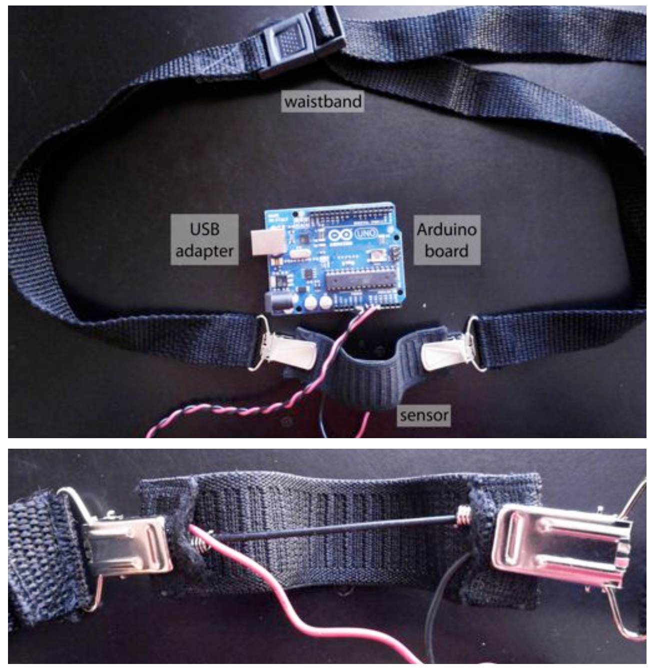

Figure 1: (Top) The adjustable sensor band with the Arduino *Uno* board. (Bottom) Close-up of the stretch sensor held in place by two clips.

Wizard-of-Oz Prototype

We first created a Wizard-of-Oz prototyping tool to assess qualitative reactions to different forms of feedback. The researcher would sit behind the user as they worked at their desk and we would manually observe the user's breathe rate due to chest rises. They would approximate the rate and input it using a slider onto a web form. The pacing prototype installed on the user's computer read this data from the webpage and updated its current user breath rate accordingly.

An important early consideration was whether feedback should be integrated into a specific application (e.g., programming IDE, web browser, or productivity software) or system wide. Because information work involves multiple applications, we opted for the latter.

We used visual pacing because information workers often listen to music and work in social areas. The first prototype used the common method of a pulsing circle atop other windows in the top-right screen corner as pacing stimulus.

Using this prototyping method on ourselves and with several users in our lab, we found two primary issues. First, though seemingly useful, real-time feedback regarding one's breath rate is highly distracting, as users frequently check the accuracy of the detected rate. Second, the rate of the pulsing circle was not noticeable when users were deeply engaged in their work, even when we exaggerated the pulse rate.

User Interface

The final design does not require any mouse- or keyboard-based interaction and does not require researcher interaction. We implemented three pacing techniques and a calibration mode. 'Screen Dim Feedback' sets the pacing stimuli to dim the entire screen from near-black to maximum brightness at the target rate. 'Menu Dim Feedback' does the same but only to the Mac OS menu bar. 'Bounce Feedback' uses an animated horizontal bar to pace respiration (see below). The calibration mode option toggles the display of a gray bar whose y-position is controlled in near real-time by the resistance of the stretch sensor. In calibration mode, the user can determine if the gray bar is indeed moving up and down as they breathe or if the band requires tightening or repositioning.

Pacing Respiration Peripherally

We implemented and tested a pulsing light technique, two dimming techniques (screen and menu bar) and one object animation technique. We chose the animation technique because it is recommended to biofeedback practitioners [7] and performed best in our early tests: users could identify clear end points to inhalation and exhalation in their periphery.

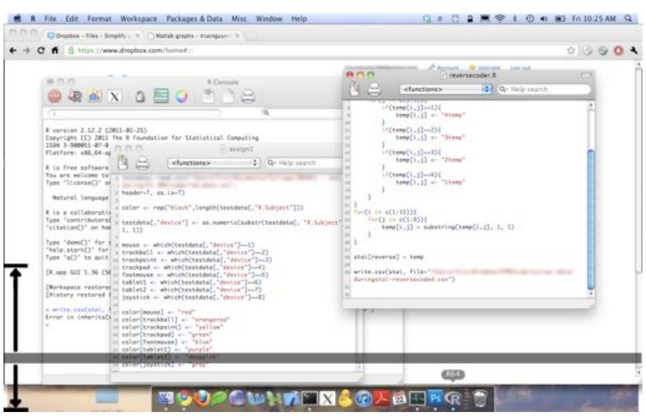

Figure 2: The peripheral paced respiration feedback used an animated, semi-translucent grey bar stretching across the screen. Vertical arrows on the left indicate the full range of motion.

The object animation technique (Figure 2) works by moving a screen-wide, semi-translucent grey bar up and down across the screen, representing inhalation (up) and exhalation (down). The ratio of up to down is 1:1. Slow-in and slow-out animation [6] is used to provide smooth movements and aid tracking. The bar moves across the lower third of the screen to reduce both distraction and distance travelled (using the full screen height would require a fast and distracting animation).

Each user's target breath rate is set relative to an individual resting baseline, rather than a universal target that might require too much effort [21]. The target rate is set to 20% below their baseline to exaggerate the slow rhythm of resting breath.

The software continuously samples sensor data and determines when to display visual feedback. If the user's current breath rate is 20% above their resting rate, pacing is triggered. The software will also automatically trigger pacing at least once every six minutes. Similar to prior studies, we use a 2-minute duration [2, 19]. After each pacing period (during which the user is expected to be able to carry on with existing work), a score is calculated. The score (displayed in the menu bar) is the normalized sum of the percent difference between user and target breath rates over that 2-minute period.

We conducted an experiment to evaluate the efficacy and feasibility of using a PPR system to pace users' respiration to a resting rate while authentically engaged in information work.

EXPERIMENT

Our experiment was designed to determine if PPR influences user respiration across computing tasks in a naturalistic manner. We recruited participants who had existing work to do (e.g. research, programming, writing). We recruited thirteen university students (9 male, 4 female, mean age=25.5 yrs) from computer science and related disciplines to participate. We told them they could conduct their existing work during the experiment. We wanted participants to be genuinely engaged and to work naturally (i.e., switch windows and tasks as they normally do). Participants were not compensated. According to our post-study questionnaire, no participants had existing respiratory conditions.

We conducted a counterbalanced, within-subjects experiment in which participants were exposed to two conditions: (1) no feedback and (2) PPR feedback. As a control, participants wore the respiration sensor in both conditions.

Procedure

Participants first wore the sensor band and the administrator tightened it. They were told that the sensor measures their respiration. A short calibration period ensured the band was positioned accurately. Participants sat in a chair in front of their laptops, working alone and not speaking. Their posture was not controlled, again to ensure a naturalistic testing environment. Hence, they were allowed to lean backwards and forwards in the chair, which can have an effect on respiration rate [19].

Participants first completed a pre-survey and consent form. As in prior studies [8], participants were then asked to close their eyes for 3-minutes and relax. Unbeknownst to participants, baseline data was collected during this relaxation period. Three participants did not take part in the relaxation period; their baseline was recorded as they completed a pre-survey.

After recording the baseline, the experiment began with the participant being told they could start working on their own tasks. They were also told that when the gray bar appeared, it represents their *target* breath rate.

To guarantee that pacing would occur at least three times during the PPR condition (at least once every six minutes), the duration of each condition was 20 minutes. When activated, PPR occurred for 2 minutes.

RESULTS

The raw respiration signal, filtered signal, and detected peaks (i.e., inhalation endpoints) are shown over a period of 30 seconds in Figure 3. Breath rate (bpm) is calculated by counting the number of inhalations in one minute. Due to the presence of high-frequency noise, we smoothed the signal using a Hanning window. The window width is selected based on a reasonable maximum breath rate of 40bpm. The peaks are detected by comparing the value of each data point in the filtered signal to data points taken immediately before and after that point. The breath rate is then calculated based on the number of peaks in a 30sec interval proceeding that time.

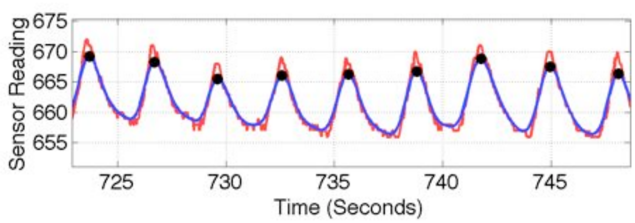

Figure 3: The raw signal (red), shown filtered (blue) and with peaks (black) detected.

Consistent with prior studies, the mean breath rate across conditions was 16.67bpm (SD=4.28) and the breath rate of the relaxation period baseline was 9.33bpm (SD=5.31).

Figure 4 (top) shows the mean for each condition with 95% confidence intervals. We conducted a paired t-test to compare the means of each condition. We found a significant difference between no-feedback (M=17.58, SD=4.18) and PPR (M=15.7, SD=4.49) conditions; $t(12)= 3.83$, $p<0.005$. The mean difference between conditions was 1.8bpm.

Figure 4 (bottom) shows the mean breath rate during the PPR condition when PPR was active or inactive. We conducted a paired t-test to compare the means between when PPR was activated (M=14.96, SD=4.44) and when it was not (M=17.09, SD=5.25); t(12)=t3.5647, $p<0.005$. The mean difference was 2.13bpm. The mean proportion of time that the feedback was activated was 0.60 (SD=0.14).

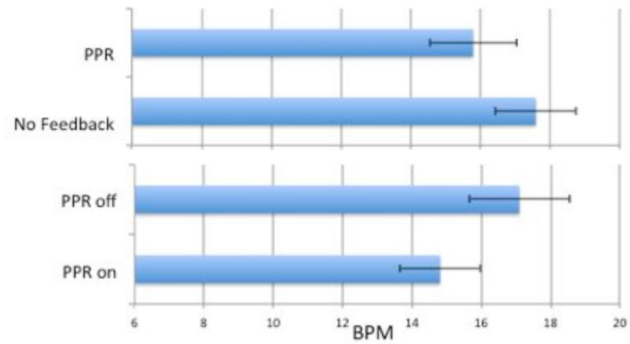

Figure 4: (Top) Mean breath rate for the No Feedback and PPR conditions with standard error bars. (Bottom) Mean breath rate during the PPR condition when PPR was on and off.

We also conducted a paired t-test to compare the breath rate in the PPR condition when feedback was unavailable (M=17.09, SD=5.25) and the breath rate during the no-feedback condition (M=17.58, SD=4.18); t(12)=0.989, $p>0.05$. When feedback was not present, breath rates returned to their working rates.

To illustrate how the breath rate is impacted by PPR, Figure 5 depicts the breath rate of one participant in each of the conditions. The no-feedback condition (top) shows a relatively consistent, high breath rate. While PPR was active (bottom) the breath rate decreased.

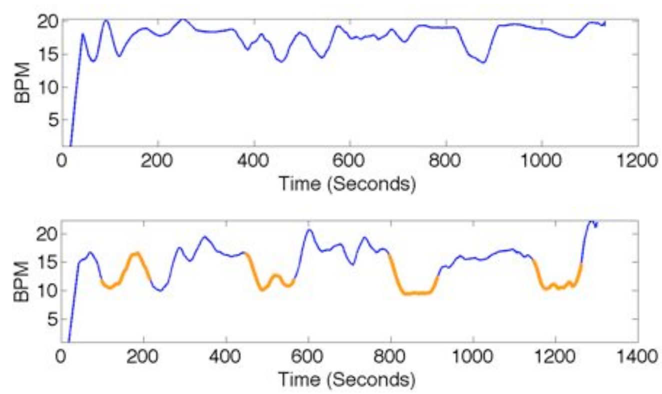

Figure 5: Breath rate for one participant in both no feedback (top) and PPR (bottom) conditions. Bold (orange) areas indicate where PPR occurred.

Using Likert scales from 1 to 5, participants rated the 'annoyingness' of PPR 2.0 (SD=0.87). Concerning how much it adversely affected productivity, PPR was rated 2.2 (SD=0.6). Lastly, participants gave a score of 3.7 (SD=1.0) as to how likely they would be to use the software all day long while working, were the sensor non-invasive.

DISCUSSION AND FUTURE WORK

Our hypothesis that PPR influences user respiration while engaged in naturalistic tasks is supported; the peripheral feedback reduced breath rate significantly. The 1.9bpm difference is close to the 2bpm interval changes shown by

Song and Lehrer to correspond with significantly higher heart rate variability amplitude [20].

Breath rates were observed to return to working levels between pacing instances. Hence, there was no evidence of persistent rate change. This is a viable area for future study; cues, social feedback, and game mechanics, among other methods, could help motivate users to maintain low respiratory rates as they work.

Based on self-report data, PPR feedback was not too distracting and participants expressed motivation to use PPR for sustained periods in the future. The results motivate longitudinal research that attempts to motivate, trigger, or incentivize users to pace their respiration even when pacing is not active. This allows for long-term respiration pacing that could complement existing methods of respiratory habit-change. The pacing algorithm could factor in the physiological and work history of the user. Such ‘context-sensitive biofeedback’ could be used to influence the physiological factors underlying user experience, focus, and affect.

Quantitative measures of the level of distraction caused by PPR (such as working while pacing) were not collected in this study. Further, the PPR method used goes beyond breath rate and implicitly proposes time and duration for inhalation and exhalation, which is beyond our goals and may have required greater effort than is necessary. This presents an opportunity for future work to identify the optimal balance between pacing efficacy and distraction.

As a tertiary contribution, to our knowledge this study is the first to quantify the effect of naturalistic information work on respiration rate. In our case, resting breath rate was almost half the working rate. This result highlights the issue of mild but chronic stress that occurs during information work, and again recommends longitudinal studies.

CONCLUSION

This paper presented the design of a peripheral paced respiration technique and evaluated its efficacy in a naturalistic task environment. We found that peripheral pacing significantly reduces breath rate, but these changes are not sustained for the duration of the tasks. The results motivate further research on incorporating biofeedback and physiological training into the operating system to complement long durations of information work, hopefully reducing users’ stress and tension.

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