Toward Breathing Edges: A Prototype Respiration Entrainment System for Browser-based Computing Tasks

Matthew Louis Mauriello, Marco Mora-Mendoza, Pablo Paredes
Pervasive Wellbeing Technology Lab | Stanford University
[mattm401, marcom3, pparedes]@stanford.edu

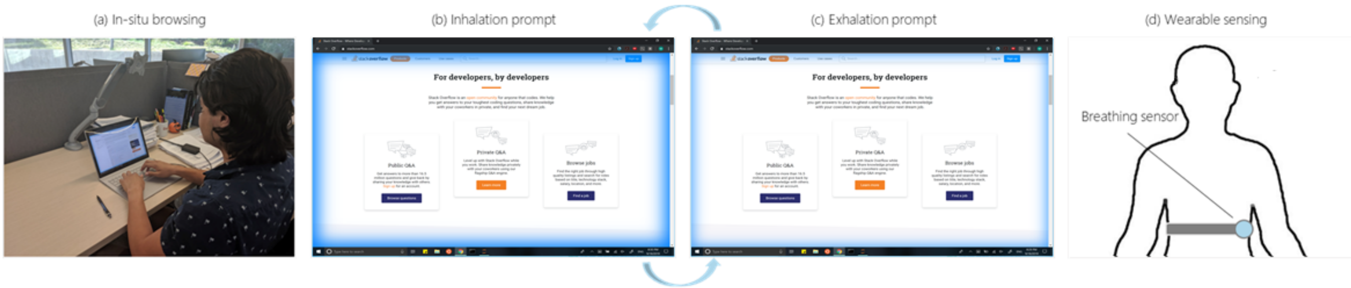

Figure 1. ***Breathing Edges*** **overview and description.** ***Left to right:*** **(a) Realistic environment setting for system usage; (b-c) Transition cycle of an active browser window between (b) inhalation (c) and exhalation prompts; (d) Position of wearable sensor on a user for monitoring physiological response.**

ABSTRACT

Increasing levels of work-related stress are pervasive among US workers leading to decreased wellbeing, lower productivity, and poor long-term health outcomes. Controlled breathing exercises can be an effective way of managing stress. However, they often require focused attention from the user, distracting them from their tasks. In this workshop paper, we present *Breathing Edges*—a browser plugin designed to help mitigate stress. The plugin attempts to turn the browser into an *entrainment tool* (*i.e.,* a tool able to alter physiology via indirect stimulus without conscious participation from the user) by injecting a dynamic color gradient animation into the periphery of the active browsing window that emulates rhythmic breathing toward helping users maintain a calm state. Through an exploratory, mixed-methods study (N=16) we investigate performance changes, distraction, and usability during two reading comprehension tasks. Results highlight the potential of this approach and we discuss design implications.

Author Keywords

Peripheral user interfaces; Controlled respiration; Entrainment; Pervasive wellbeing; Affective computing

CCS Concepts

•**Human-centered computing** → **Human computer interaction (HCI);** User studies;

If you wish to discuss the research, please contact the Pervasive Wellbeing Technology Lab at Stanford University by emailing: pparedes@stanford.edu.

Workshop 27: The 3rd Body as a Starting Point Workshop - Exploring Themes for Inbodied Interaction Research and Design
CHI'20, April 25–30, 2020, Honolulu, HI, USA

INTRODUCTION

Increasing levels of work-related stress are pervasive among US workers leading to decreased wellbeing, lower productivity, and poor long-term health outcomes [33]. Data from the American Psychological Association (APA) survey on stress (2013) has shown that people find it difficult to manage their work-related stress due to a lack of time or a lack of will [2]. As a result, there have been a number of recent proposals aimed at managing stress (arousal) by leveraging biofeedback [18], encouraging movement [30], and adapting breathing exercises [4, 31] to create novel interactions that repurpose common, everyday experiences for stress management.

One common experience for many US workers is having to use a web browser. In 2018, the average adult in the US spent approximately four hours each day using web browsers on their computers and mobile devices —a number that is only expected to increase with time [36]. Browsers allow users to perform a myriad of tasks online, the most common include: (i) responding to email, (ii) messaging on social media, (iii) watching videos, and (iv) researching topics of interest [35, 32]. This ubiquity suggests web browsers are an ideal platform for delivering a subtle, stress management intervention.

In this workshop paper, we present *Breathing Edges*—a plugin designed to help mitigate stress using a web browser. The plugin attempts to turn the browser into an *entrainment tool* (*i.e.,* a tool able to alter physiology via indirect stimulus without conscious participation) by injecting a dynamic color gradient animation into the periphery of the active browsing window that emulates rhythmic breathing toward helping users maintain a calm state. As part of our research, we ask: *Is peripheral entrainment an effective stress intervention? Does it distract users from their tasks? And, what challenges and benefits do they perceive about using the tool during future web browsing?*

To address these questions, we conducted an exploratory, mixed-methods study (N=16) using a counterbalanced, within-subjects design. We investigate performance changes, distraction, and the usability of our tool during two reading comprehension tasks and complement this data with qualitative feedback from surveys and brief, semi-structured interviews. Our results indicate that approximately 75% of participants were able to lower their breathing rates during a stressful reading task and generally ascribed a calming effect to engagement while the remaining 25% had an opposite physiological response. Interestingly, most participants agreed that *Breathing Edges* was subtle and would use it in the future.

BACKGROUND AND RELATED WORK

Here, we provide background on stress as well as discuss research on breathing interventions and precision health.

Background on Stress

The stress response is an evolutionary mechanism that mobilizes physical resources to help humans cope with challenges. In that sense, we understand stress as a psycho-physiological response to a stressor. The American Psychological Association (APA) differentiates between acute, episodic acute, and chronic stress [3]. In the short term, acute or daily stress has been shown to cause changes in biomarkers (*i.e.,* measurable substances in the body whose presence is indicative of some phenomenon) within the day of the stressor [12]. Moreover, daily stress has been shown to exacerbate symptoms of existing physical health conditions [1, 25]. Our work aims to repurpose a user's web browsing for reducing accumulated stress while mitigating new stressors that might exacerbate stress-related symptoms using a breathing intervention tool.

Breathing Interventions and Entrainment

Breathing interventions are increasingly being evaluated as low cost, efficacious forms of treatment for medical conditions like hypertension [29], high blood pressure [13], and stress management [24]. Most interventions fall into two categories: teaching a breathing technique (*e.g.,* yogic breathing [24]) or using devices to coach users *in-situ* (*e.g.,* [21]) towards goals like fostering new coping skills that allow patients to manage the symptoms of their condition. However, results vary with some responding to intervention more positively than others. One reason for this variation is that there is no standard resting human breathing rate, which makes calibrating these interventions difficult. For example, resting breathing rates for adults can vary between 12-20 Breaths Per Minute (BPM) and an already low breathing rate is more difficult to change [8]. However, if an intervention is successful in decreasing these rates then there should be an observable increase in Heart Rate Variability (HRV) typical of a calmer mental state [5, 31].

Prior work has explored peripheral guided breathing (*i.e.,* placing objects on the edge of a user's screen that animate in such a way as to simulate a targeted breathing rate) to assist users with stressful tasks *in-situ* [10, 28, 26]. The use of peripheral vision to trigger intervention is viewed as beneficial because it lowers the cognitive load of engagement [19]. It is also theorized that stimuli presented in this way—particularly color—can activate the parasympathetic nervous system to create a feeling of calm [39]. However, entrainment was not necessarily the goal of prior work and measures of distraction caused by such systems have largely been subjective. We extend prior work by investigating a system that entrains users (*i.e.,* alters physiology via indirect stimulus without conscious participation) towards a subtle, non-distracting intervention.

Precision Health and HCI

Research in health often focuses on the treatment of disease. This results in patients being treated once symptoms have manifested. In many cases, however, early detection and intervention is important. However, there are a number of barriers including that frequent health screening is not tenable with current infrastructure and resources are limited. As a result, there are calls from within the precision health movement to shift focus away from treatment to prevention using technologies that support proactive health and could potentially increase screening for different conditions [20, 9, 6]. These goals align well with the existing body of work in HCI and design that focuses on the development of new screening tools (*e.g.,* [37, 38, 22]), methods for interacting with health data (*e.g.,* [27, 23]), and persuasive technologies for behavior change (*e.g.,* [7, 17]). This wide range of technologies often makes it easier for people to access information and treatment in ways that work for them. However, patients themselves often do not engage in preventative health and wellbeing improvement measures due to a lack of time or a lack of will [2]. Thus, as these technologies become increasing relied upon by users and health communities, it is clear that there will be an increasing number of opportunities for HCI researchers to help improve adoption, results, and interactions with healthcare providers having a significant impact on public health.

DESIGN AND IMPLEMENTATION

Breathing Edges is a browser plugin designed to turn a web browser into an *entrainment tool* capable of modulating breathing (*i.e.,* toward goals like helping reduce arousal/stress and/or increasing cognitive performance). The tool was implemented in the Google Chrome™ [11] browser and it updates the CSS of any web page in the active browser window to include a dynamic color gradient along the edges of the window. This gradient pattern simulates a targeted breathing rate through an expanding/contracting animation based on a Bézier Curve (Figure 3). The use of peripheral vision allows users to process this information separately from their main task reducing the effort necessary to engage with the intervention [19]. Users can directly manipulate several parameters of the tool including the color, the opacity of the gradient, and the target breathing rate (*i.e.,* changing the speed of the animation) (Figure 4).

Early Pilot. We conducted an early pilot, when we asked participants to use the tool and provide qualitative feedback. Similar to prior work [10, 28], users in our pilot found the plugin to be helpful and non-distracting. They also reported that the animation quickly faded into the background of the web page's layout and that the color options allowed them to adjust and contextualize the intervention to suit their subjective preferences (*e.g.,* choosing a color that minimized distraction).

Figure 3. Stages of tool's animation cycle showing how the gradient pattern expands and contracts to mimic breathing when active.

STUDY METHOD

To evaluate *Breathing Edges* and investigate our research questions, we conducted an exploratory study using a mixed-methods approach. We investigated performance changes, distraction, and the usability of the tool during reading comprehension tasks using a counterbalanced, within-subjects study design in which participants were exposed to two conditions, one with feedback from our tool and one without (Figure 2). We also complement this data with qualitative feedback from surveys and brief, semi-structured interviews.

Recruitment. We recruited participants from our local community using university list-servs and posted flyers. We enrolled participants on a first-come, first-served basis. Once enrolled, participants reviewed our consent materials and completed a pre-study questionnaire. The pre-study questionnaire collected demographic data and assessed web browser experience.

Setup. Sessions were conducted in a naturalistic office environment (*i.e.,* a cubicle in an open-office layout near large windows looking out on a parking lot and green space) using a laptop configured to run our browser extension and communicate with our data collection hardware. We used a Zephyr Bioharness to collect physiological data (*i.e.,* BPM) [14]. Participants sat at a powered sit/stand desk in an office chair. We also provided headphones to muffle area noise.

Procedure. Upon arrival at our lab, a researcher greeted the participant and discussed the study plan before obtaining written consent. After obtaining consent, the researcher guided the participant through affixing the Zephyr Bioharness. All participants were first asked to complete a *baseline task* where they watched a relaxing video for three minutes while sitting comfortably at the desk. The researcher used this time to estimate the participant's average resting breathing rate based on the real-time data provided by the Bioharness. Participants then experienced the first of two *reading comprehension tasks* where they were given 9 minutes to complete 9 questions about three reading passages adapted from the SAT exam.

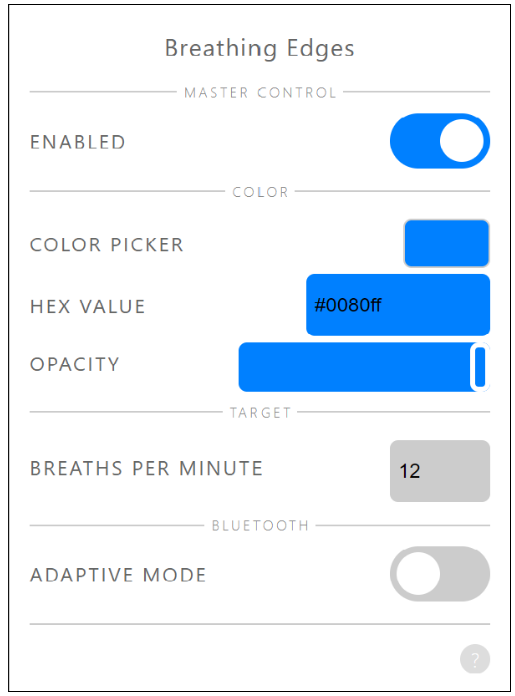

Figure 4. User interface of Breathing Edges plugin. Features include choosing edge color, opacity, and breathing rate as well as ability to establish Bluetooth connections to external sensors for "adaptive" mode.

After a three minute break, participants completed a second reading comprehension task. Depending on the assigned conditions, one of these two tasks was performed while *Breathing Edges* was active and set to a breathing rate designed to encourage slow breathing (*i.e.,* 30% lower than the participant's estimated baseline average BR). In this condition, participants were provided with a brief introduction to the tool and given two minutes to familiarize themselves with it before beginning the task itself. Between each of these three tasks participants rated their stress and perceptions of the task including the NASA Task Load Index (NASA-TLX) [15]. After finishing these tasks, participants completed a post-study questionnaire that solicited their immediate feedback on their experience (*e.g.,* whether they had noticed or been distracted by the browser extension).

Figure 2. Example study session in intervention-control sequence.

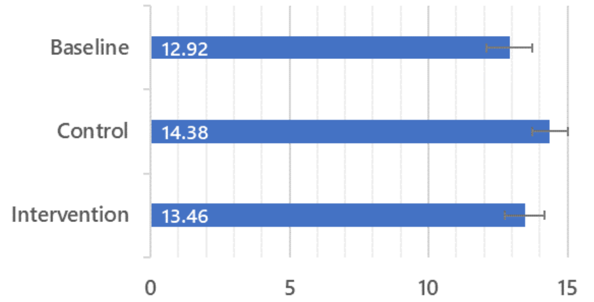

Figure 5. Average change in breathing rates (in BPM) for each of the three identified groups of participants with standard error.

STUDY RESULTS

Here, we present a preliminary analysis of our results including: physiological data, task performance metrics, self-report surveys, and debrief interviews. We report on aggregate trends.

Physiological Results. For average breathing rate (Figure 5), we observed a 11% increase over baseline in the control condition compared to a 4% increase in the intervention condition. Most participants (75%) seemed to engage with the breathing intervention as expected (*i.e.,* lowering their breathing rate several BPM) while the others (25%) increased their breathing rate during intervention. For average heart rate variability, we observe a 1% decrease over baseline in the control condition compared to a 5% increase in the intervention condition when estimated using the root mean square differences of successive heartbeat intervals (RMSSD) [34]. In aggregate, these trends are weak but consistent with related work in this area.

Task Performance. We evaluated participant performance on the reading comprehension task by looking at the average number of questions answered, how many of these answers were correct, and the average length of time spent answering these questions. Participants spent, on average, 1.13 minutes on each question in both conditions. With respect to correctness, we observe a slight increase in the percent correct in the intervention condition.

NASA-TLX Results. To get a sense of the change in the characteristics of the task during intervention, we baseline corrected and normalized results from the NASA-TLX to highlight changes (Figure 6). Trends in this data suggest that participants perceived an increased mental demand, but also report less required effort to complete the task and a decrease in physical demand. Other measures such a temporal demand, perceived performance, and frustration remain relatively unchanged with slight decreases.

Task Survey Results. In addition to the NASA-TLX, we asked participants to subjectively rate their level of perceived stress during the task. They also rated the level of concentration required to complete the task, their energy level, sentiment towards the task, and amount of muscle tension they experienced (Figure 7). These values have also been corrected for baseline and normalized. The trends in the data suggest that participants perceived slightly more stress during the intervention; however, the task took slightly less concentration to complete. When we looked at the group of participants who responded

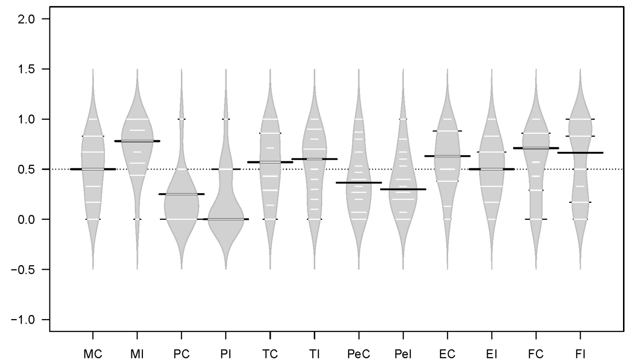

Figure 6. NASA-TLX evaluation of mental demand (M), physical demand (P), temporal demand (T), perceived performance (Pe), required effort (E), and frustration (F). Data corrected for baseline and normalized with median shown. C for control and I for intervention.

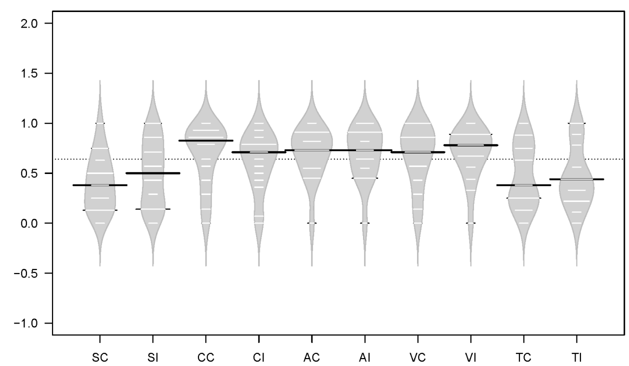

Figure 7. Subject likert evaluations of stress levels (S), require concentration (C), energy level (A), sentiment (V), and muscle tension (T). Data corrected for baseline and normalized with median shown. As before, C and I for control and intervention, respectively.

negatively to the intervention, we find that they rated their perceived stress high during the intervention condition, compared to their counterparts—their ratings of perceived stress were relatively unchanged across conditions.

Perception of Tool. Overall, perceptions of the tool were positive. Most participants (75%) considered the tool to be non-distracting. The majority (56%) found the tool to be subtle and one participant thought it was "too" subtle. This is unsurprising as half (50%) reported not noticing the tool during the task when it was on and only noticed focusing on it when the tool was being introduced to them. Of those participants who noticed the tool during the reading comprehension task, half reported attempting to match their breathing to the rhythm of the animation and the others reported ignoring it entirely. A few said that noticing the edges reminded them that they needed to focus on the task which was helpful. Finally, half (50%) reported feeling calmer during the intervention.

Perception of the Task. Overall, just over half of participants (56%) reported that the task was difficult. Two participants commented that the order of the task likely influenced their performance as they both viewed the second task as easier despite being in different conditions. A few reported that they were also less motivated to complete the tasks toward the end of the session.

DISCUSSION

Through our mixed-methods approach, we evaluated *Breathing Edges*—a prototype browser plugin designed to help mitigate stress through peripheral entrainment during browser-based computing tasks. Our results suggest the tool, as an breathing intervention, may have weakly impacted participants during a reading comprehension task though additional testing and calibration of the experiment seems necessary. As it is generally thought that a lower breathing rate can encourage relaxation, the trends we observed with respect to physical demand, frustration, and required effort could be the result of this influence. However, like other interventions (*e.g.,* [10, 28]) perceptions of and reactions to the tool differ. Some participants responded differently (*i.e.,* in terms of changes in breathing rate) than expected (*e.g.,* [21]) and showed signs of increased stress when presented with the intervention of the tool. Thus, perhaps an interesting area for future work could be to detect these physiological differences in users *in-situ* and alter the intervention accordingly (e.g., by trying different BPM settings, disengaging).

Moreover, participants viewed the tool positively and many suggested improvements to increase its efficacy including those that seemed to have negative responses. Interestingly, over half thought changing the settings of the tool might improve their performance during cognitively heavy tasks and the influence of the tool—which they described as calming. Prior work has investigated how different colors can stimulate changes in affect [16]. Fortunately, our tool is well-suited for this type of tuning. Thus, a next step for us to explore could be longitudinal studies that might allow us to investigate what effect the system has on users during longer, more naturalistic periods of use when they can alter the settings of the tool.

Limitations and Future Work

The limitations of this work include our sample size and population, which was small, highly educated, and very accustom to browser based computing tasks—in a sense this makes them appropriate for early work like ours, but their reactions and perceptions of the tool are likely not representational. Additionally, perceptions of our reading comprehension task (which was an artificial stressor) differed including those who viewed it as very stressful and those that did not which should be addressed in future studies.

ACKNOWLEDGMENTS

The authors thank our pilot users and student volunteers for their contributions—particularly Jonathan Burkle, Hugo Alayrangues, and Andrea Shulman. We also wish to recognize the support provided by Professor James Landay as well as the Precision Health and Integrated Diagnostic Center (PHIND).

REFERENCES

[1] David M. Almeida. 2005. Resilience and Vulnerability to Daily Stressors Assessed via Diary Methods. *Current Directions in Psychological Science* 14, 2 (2005), 64–68.

[2] American Psychological Association. 2013. Are Teens Adopting Adults' Stress Habits? (2013).

[3] APA. 2019. *The different kinds of stress. American Psychological Association.* `https://www.apa.org/helpcenter/stress-kinds`

[4] Stephanie Balters, Elizabeth L Murnane, James A Landay, and Pablo E Paredes. 2018. Breath Booster! Exploring In-car, Fast-paced Breathing Interventions to Enhance Driver Arousal State. *Proceedings of the PervasiveHealth Conference* (2018).

[5] Luciano Bernardi, Joanna Wdowczyk-Szulc, Cinzia Valenti, Stefano Castoldi, Claudio Passino, Giammario Spadacini, and Peter Sleight. 2000. Effects of controlled breathing, mental activity and mental stress with or without verbalization on heart rate variability. *Journal of the American College of Cardiology* 35, 6 (2000).

[6] Francis S Collins and Harold Varmus. 2015. A new initiative on precision medicine. *New England journal of medicine* 372, 9 (2015), 793–795.

[7] Steven Dorrestijn and Peter-Paul Verbeek. 2013. Technology, wellbeing, and freedom: The legacy of utopian design. *International Journal of Design* (2013).

[8] Tracy Flenady, Trudy Dwyer, and Judith Applegarth. 2017. Accurate respiratory rates count: So should you! *Australasian Emergency Nursing Journal* 20, 1 (2017).

[9] Sanjiv Sam Gambhir, T Jessie Ge, Ophir Vermesh, and Ryan Spitler. 2018. Toward achieving precision health. *Science translational medicine* 10, 430 (2018).

[10] Asma Ghandeharioun and Rosalind Picard. 2017. BrightBeat: effortlessly influencing breathing for cultivating calmness and focus. In *Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems*. ACM.

[11] Google Inc. 2008. Google Chrome. (2008). `https://www.google.com/chrome/`

[12] Jean-Philippe Gouin, Ronald Glaser, William B. Malarkey, David Beversdorf, and Janice Kiecolt-Glaser. 2012. Chronic stress, daily stressors, and circulating inflammatory markers. *Health Psychology* 31, 2 (2012).

[13] E Grossman, A Grossman, MH Schein, R Zimlichman, and B Gavish. 2001. Breathing-control lowers blood pressure. *Journal of human hypertension* 15, 4 (2001).

[14] Jono Hailstone and Andrew E Kilding. 2011. Reliability and validity of the Zephyr BioHarnes to measure respiratory responses to exercise. *Measurement in Physical Education and Exercise Science* 15, 4 (2011).

[15] Sandra G Hart and Lowell E Staveland. 1988. Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In *Advances in psychology*. Vol. 52. Elsevier, 139–183.

[16] Takeshi Hatta, Hirotaka Yoshida, Ayako Kawakami, and Masahiko Okamoto. 2002. Color of computer display frame in work performance, mood, and physiological response. *Perceptual and motor skills* 94, 1 (2002).

[17] Eric B. Hekler, Predrag Klasnja, Jon E. Froehlich, and Matthew P. Buman. 2013. Mind the Theoretical Gap: Interpreting, Using, and Developing Behavioral Theory in HCI Research. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '13)*. Association for Computing Machinery, New York, NY, USA, 3307–3316. DOI: http://dx.doi.org/10.1145/2470654.2466452

[18] Javier Hernandez, Daniel McDuff, Xavier Benavides, Judith Amores, Pattie Maes, and Rosalind Picard. 2014. AutoEmotive: bringing empathy to the driving experience to manage stress. In *Proceedings of the 2014 Companion Publication on Designing Interactive Systems*. ACM, 53–56.

[19] Deborah Lott Holmes, Karen M Cohen, Marshall M Haith, and Frederick J Morrison. 1977. Peripheral visual processing. *Perception & Psychophysics* 22, 6 (1977).

[20] Muin J Khoury, Michael F Iademarco, and William T Riley. 2016. Precision public health for the era of precision medicine. *American journal of preventive medicine* 50, 3 (2016), 398.

[21] Diana MacLean, Asta Roseway, and Mary Czerwinski. 2013. MoodWings: a wearable biofeedback device for real-time stress intervention. In *Proceedings of the 6th international conference on PErvasive Technologies Related to Assistive Environments*. ACM, 66.

[22] Mark Matthews, Saeed Abdullah, Elizabeth Murnane, Stephen Voida, Tanzeem Choudhury, Geri Gay, and Ellen Frank. 2016. Development and evaluation of a smartphone-based measure of social rhythms for bipolar disorder. *Assessment* 23, 4 (2016), 472–483.

[23] Matthew Louis Mauriello, Ben Shneiderman, Fan Du, Sana Malik, and Catherine Plaisant. 2016. Simplifying Overviews of Temporal Event Sequences. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA '16)*. ACM, New York, NY, USA, 2217–2224.

[24] Kevin D McCaul, Sheldon Solomon, and David S Holmes. 1979. Effects of paced respiration and expectations on physiological and psychological responses to threat. *Journal of Personality and Social Psychology* 37, 4 (1979), 564.

[25] Robert R. McCrae. 1984. Situational determinants of coping responses: Loss, threat, and challenge. *Journal of Personality and Social Psychology* 46, 4 (1984).

[26] D Scott McCrickard, Richard Catrambone, and John T Stasko. 2001. Evaluating Animation in the Periphery as a Mechanism for Maintaining Awarness.. In *INTERACT*.

[27] Megan Monroe, Rongjian Lan, Juan Morales del Olmo, Ben Shneiderman, Catherine Plaisant, and Jeff Millstein. 2013. The Challenges of Specifying Intervals and Absences in Temporal Queries: A Graphical Language Approach. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '13)*.

[28] Neema Moraveji, Ben Olson, Truc Nguyen, Mahmoud Saadat, Yaser Khalighi, Roy Pea, and Jeffrey Heer. 2011. Peripheral paced respiration: influencing user physiology during information work. In *Proceedings of the 24th annual ACM symposium on User interface software and technology*. ACM.

[29] Monika Mourya, Aarti Sood Mahajan, Narinder Pal Singh, and Ajay K Jain. 2009. Effect of slow-and fast-breathing exercises on autonomic functions in patients with essential hypertension. *The journal of alternative and complementary medicine* 15, 7 (2009).

[30] Pablo Enrique Paredes, Nur Al-Huda Hamdan, Dav Clark, Carrie Cai, Wendy Ju, and James A Landay. 2017. Evaluating In-Car Movements in the Design of Mindful Commute Interventions: Exploratory Study. *Journal of Medical Internet Research* 19, 12 (2017).

[31] Pablo E Paredes, Yijun Zhou, Nur Al-Huda Hamdan, Stephanie Balters, Elizabeth Murnane, Wendy Ju, and James A Landay. 2018. Just Breathe: In-Car Interventions for Guided Slow Breathing. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 2, 1 (2018).

[32] Pew Research Center. 2010. Online Activities. (2010). www.pewinternet.org/2010/12/16/online-activities/

[33] Jeffrey Pfeffer. 2018. *Dying for a paycheck: How modern management harms employee health and company performance—and what we can do about it*. HarperCollins.

[34] Fred Shaffer and JP Ginsberg. 2017. An overview of heart rate variability metrics and norms. *Frontiers in public health* 5 (2017), 258.

[35] Statista. 2018. Most popular online activities of adult internet users in the United States as of November 2017. (2018). https://www.statista.com/statistics/183910/internet-activities-of-us-users/

[36] The Nielsen Company. 2018. Time Flies: U.S. Adults Now Spend Nearly Half A Day Interacting with Media. (2018). https://www.nielsen.com/us/en/insights/article/2018/time-flies-us-adults-now-spend-nearly-half-a-day-interacting-with-media/

[37] Edward Jay Wang, Junyi Zhu, Mohit Jain, Tien-Jui Lee, Elliot Saba, Lama Nachman, and Shwetak N Patel. 2018. Seismo: Blood pressure monitoring using built-in smartphone accelerometer and camera. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. ACM, 425.

[38] Edward Jay Wang, Junyi Zhu, William Li, Rajneil Rana, and Shwetak Patel. 2017. HemaApp IR: noninvasive hemoglobin measurement using unmodified smartphone cameras and built-in LEDs. In *Proceedings of the 2017 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2017 ACM International Symposium on Wearable Computers*.

[39] Bin Yu, Jun Hu, Mathias Funk, and Loe Feijs. 2018. DeLight: Biofeedback Through Ambient Light for Stress Intervention and Relaxation Assistance. *Personal Ubiquitous Comput.* 22, 4 (Aug. 2018), 787–805.