Collective Stress Visualization Enabled by Smart Cushions for Office Chairs

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Abstract. This paper explores the possibility of combining sensory data of multiple individuals into a collective visualization. Using a smart cushion for office chairs that collects several stress-related parameters, namely: heart rate, respiratory rate, and heart-rate variability, individuals' data can be aggregated into a collective stress visualization. Three different visualizations are designed which abstractly, grouped and aggregated, and metaphorically visualize the collective stress. Additionally, two more visualizations are explored for the 'new way of working' during the COVID-19 epidemic, where people work remotely and from the office. Through expert and user interviews, these visualizations are evaluated. Additionally, there is researched on whether measured heart-rate variability can predict perceived stress levels. The results found an inversed correlation than hypothesized.

Keywords: Collective stress · Stress visualization · Smart cushion · Ballistocardiograph sensor

1 Introduction

At more and more places, data of individuals is collected. While this data can provide value for these individuals personally, we might combine these individuals' data and create value for the collective. In, for example, offices, daily interactions take place, and well-being is an important topic. Wellbeings' data of individuals combined and aggregated into a collective visualization might add value for collective reflection.

This paper explores how to visualize collective stress by using smart cushions for office chairs. Collective stress in the office is defined as occupational, workgroup level stress which is caused by either a shared stressor (e.g., an approaching deadline) or by other people (e.g., the facial expression of a colleague) [1]. We explore how one can use multiple individuals' collected well-being data to design collective stress visualizations.

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User research and expert evaluation are done into the associations and experiences with collective visualizations. Additionally, we researched if perceived stress can be predicted through heart rate variability data.

2 Related Work

The current office environment has seen a rapid change in the last decade. Office buildings, the companies who occupy them, and their workforce have always been a discussion ground [2–4]. Nevertheless, the satisfaction and well-being of the workforce have always been considered, as a negative change can have a considerable impact on the workforce and therefore influence its productivity [4].

An example of technologies that provide insights into processes and well-being is the integration of sensors and Internet of Things-enabled devices in the office [5]. Integrating these devices generates data of every individual in the building and can be valuable if visualized the correct way [6]. These visualizations can give insights on several levels of the office, ranging from insights on a more individual level to combining these single employee's data into collective visualizations.

Several visualizations systems are designed primarily to improve well-being on the work floor, which provide both the individual employee with systems where they can track and reflect on their well-being, to systems that provide teams and departments with means to track and reflect on the collective health status.

Different efforts have been made in creating design proposals that should help individuals track their well-being. Snyder and others tried to create a system that visualizes a person's arousal level [7]. Others tried to create bio-feedback systems which visualize stress [8, 9]. Other researchers focus on making systems that collect individual data and transforms the datasets into collective visualizations to create a reflective process for the complete work floor [10–12].

3 Smart Cushion Design

The study was performed using the smart cushion for office chairs with the model number LS-AEA from BOBO Technology (Fig. 1). A piece of PVDF (Polyvinylidene Fluoride) film is integrated into the smart cushion to capture the BCG signals from the users.

The smart cushion includes a Wi-Fi Module to transmit the collected BCG signals to the BOBO Technology's cloud server. BOBO Technology's cloud server provides data analysis services to calculate users' vitals based on BCG signals received. Typically for the smart cushion (Model LS-AEA), the output includes heart rate, respiratory rate, and heart rate variability. The heart rate variability index is usually treated as a valued indication of stress. Additionally, BOBO Technology's cloud server provides an OpenAPI, in which the data can be easily accessed through the OpenAPI. The outputs are stored in an InfluxDB database for further analysis within this study.

Fig. 1. *Left* - smart cushion on an office chair. *Right* - user working on the smart cushion (grey)

4 Data Visualization

Three levels of visualizations were identified on which any technology could add value. Firstly, on an individual level, the tech can generate insights into a person's well-being or productivity levels. Secondly, on a collective level, one visualization shows multiple individuals' merged data (for example, working together in one room or department). Thirdly, combining the data of multiple collectives can generate insights into the entire office or company.

Visualizing on a collective level provides several design opportunities. Data can be visualized in several ways as data generated is from several individuals, and thus can be displayed by either leaving the individual data intact and still visualizing individuals as a collective or by aggregating the data and combining the data into a 'more' collective visualization. Additionally, data can be displayed either more abstractly and factually using colors and size or designed through metaphors.

Furthermore, the COVID-19 epidemic presented a unique opportunity to design for changing office cultures and environments. As collective are not always in one place, the office floor, but also range to home offices, design opportunities arise to design collective visualizations that extend from the office floor into the home office or vice versa.

The above design suggestions are further explored through expert evaluation and user evaluation. Several collective health visualization designs are evaluated in two sessions with one expert on collective visualization and two young professionals.

4.1 Collective Visualizations

Mosaic Visualization (Abstract) (Fig. 2)

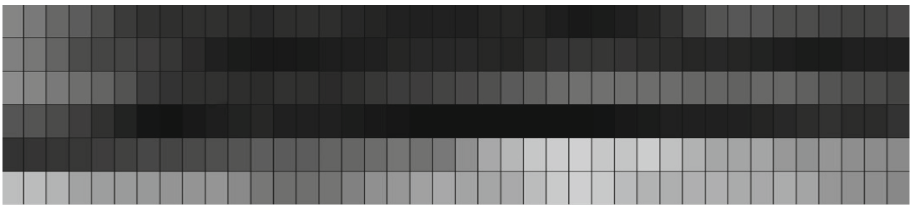

Fig. 2. Every block indicates one person their stress-related levels measured over one hour. Visualizations display thus a week's worth of data.

Expert Evaluation. The time dimension of the mosaic visualization is the most valuable of this visualization. Users can see an extended range of days. Thus, it is possible to reflect upon their stress levels on a short-term and long-term basis due to color usage and the number of people listed. Due to the greyness, it looks like a 'misty' landscape. The greyness adds a layer of negativeness to the already negative message of too much stress.

Bar Visualization (Aggregated And Grouped) (Fig. 3)

Fig. 3. Data is mapped per day, where five working days are visualized in this picture. In this visualization, it is apparent that there have been higher stress levels for multiple days as the red bar has the most significant size on the third day. After this day, people are slowly starting to recover from the stress, consequently increasing the size of the green bar. (Color figure online)

Expert Evaluation. There is a low learning effort due to color usage. Green means relaxed, and red means worse. Besides, the colors are also less 'stress-full' compared to the grey shades. It is essential to inform people about the meaning of the visualization. What does it mean if they are in, for example, the green or orange zone? Individuals cannot see data about themselves; thus, it might be more valuable for managers, as the visualization shows aggregated data and the collective's overall state.

Cityscape Visualization (Metaphor) (Fig. 4)

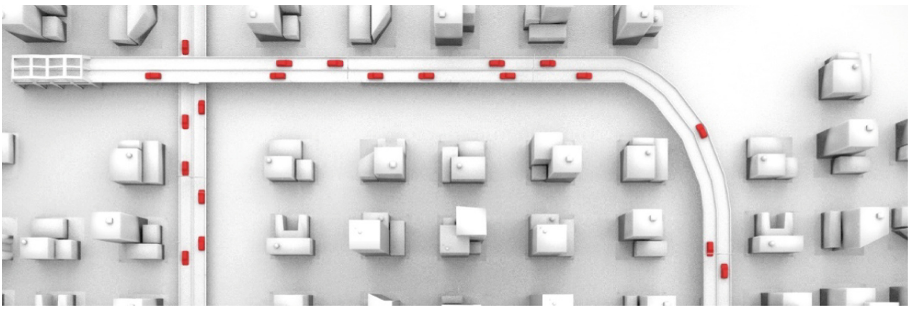

Fig. 4. The number of cars is linked to the amount of traffic. The visualization visualizes traffic jams as a metaphor for stress. The more cars are getting on the road, the more people are stressed.

Expert Evaluation. It is ambient; it will perform in the office environment as a canvas. The visualization will not grab too much attention and make a stressful situation even more stressful. Individual users might have difficulty understanding their stress levels, as their information is not visible.

Overall Evaluation. There are several takeaways from the experts' evaluation: data visualizations must have a versatile time range, which helps users reflect both short-term and long-term. Colors have immense importance; they can negatively influence the user and help understand the data more quickly. Additionally, more aggregated data can be helpful to understand the collective.

4.2 "The New Way of Working" – Visualizations

Two visualizations are proposed, which should help employees and managers reflect on their stress status. These visualizations build upon the already identified takeaways.

Additionally, in these visualizations, the aspects of the COVID-19 epidemic are considered. Several researchers and companies indicate that office and work life will permanently change, and people will be working more remotely [13]. While all employees indicate that they will enjoy their work at home, they risk becoming disconnected from the company and their colleagues.

In both visualizations, the main element visible is the stress visualization itself. It is an abstract representation that tries to summarize one's arousal level. Every horizontal row represents a single employee or user, and every vertical row a single day. The color indicates one's performance level based on the Yerkes-Dodson Law [14], which describes the relationship between arousal levels and performance levels (Fig. 5). In the designed collective visualization, the color is based on this principle. Due to this color differentiation, it is immediately clear if the pressure is too high. Thus, employees directly reflect upon these strains. In addition, four weeks of data are visible so that trends will be visible in the data.

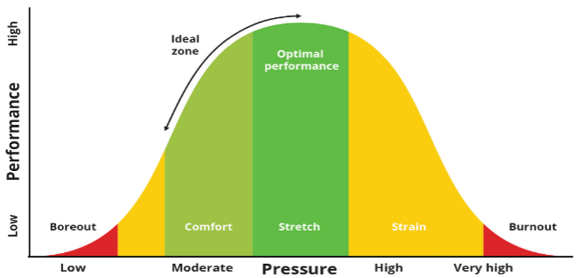

Fig. 5. Yerkes-Dodson law (Cohen [14]) – describes the relationship between pressure and performance

Collective Visualization. In addition to the main performance visualization, the interface allows employees to indicate their emotions. These emotions are ordered based on whether they were sent at home or the office space. The extra addition makes the visualization a twitch more personal, as employees sitting at home and vice versa can view how their colleagues are feeling (Fig. 6).

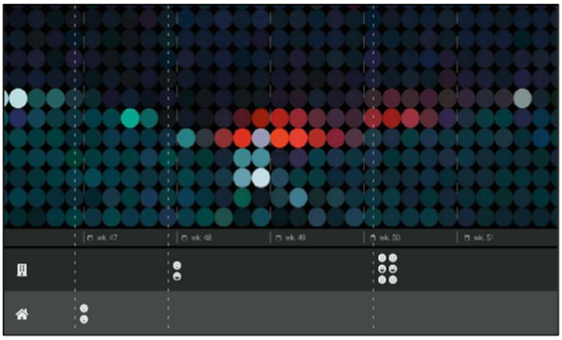

Fig. 6. Collective health visualization is accessible through a central screen and an online webpage. The upper part of the visualization shows individuals horizontally, where every dot represents one day, and the color indicates the performance level. On the bottom part of the visualization, individuals emotions are shown to add a deeper level of emotional data to the visualization.

"Online Video Call" – Collective Visualization. The video call visualization is the leading visualization displayed in the call window of any online meeting. It gives employees the means to reflect on the collective stress at any point of the meeting (Fig. 7).

Fig. 7. Collective visualization visible within an online meeting (e.g., in Microsoft Teams). The visualization shows individuals horizontally, where every dot represents one day, and the color indicates the performance level.

User Evaluation. A validation session is held to review the designed interfaces and evaluate possible users' opinions. Two young professionals were asked to review the interfaces in an open discussion session. A set of topics and questions were set up to prepare the discussions beforehand. The topics discussed were their first thoughts on the system after detailed description, in what kind of setting could the interface be val-uable, and at what point in time could this be helpful? During the session, notes were taken, and the conversation was transcribed after the session. The session was analyzed through thematic analysis, a widely used method within the design world to find themes and patterns within interviews [15]. The following themes are identified:

Identifying Individuals (Acceptance). One of the first though of both interviewees was that the chance of identifying an individual was high. One participant said it never could be anonymous, and chances are to determine who belongs to which row. Another said that if there is one red dot in the system, it is not desirable to know who that is. Additionally, both said that if 50% of the team were red, it would be impossible to solve the situation, and colleagues should take responsibility themselves.

Office Culture (Acceptance). One of the interviewees mentions that office culture needs to be ideal before one can reflect upon the data together. "what's way more important here is the culture of what organization you are working in," [...] "in the ideal world. You do not have an ass of a manager. You can just have an open conversation with him or fellow team members."

Personal Reflection. Both participants mention it might be more helpful as a personal tool: "on a personal level, I can really see this works. If I could see my own data in a personal system, I think that can really help as input for myself."

Tool for Evaluation. One participant mentioned that the tool would be ideal for evaluation after a project. If one can identify stressful periods, you can reflect upon that period with your team and improve future situations.

Aggregation of Data. Both participants said that the tool could be helpful if it aggregates the data into an average score for the entire team. "I guess it could be useful to get a rating of how the full team is doing."

Overall Evaluation. Both participants had positive opinions about the central screen visualization. The visualization within a video call was evaluated as useless, as it would only be a distraction during a meeting. Nevertheless, there are several areas where the tool could be more helpful. One could look at the potential of visualizing data on a more personal level or create a tool that supports managers and employees at the end of the project to reflect upon the stress levels during the project.

5 Effect of Perceived Stress on Measured Heart Rate Variability

Research is conducted to study a relationship between perceived stress and the measured heart rate variability. A generalized rule for predicting a user's perceived stress would mean more insightful data visualizations.

The heart rate variability (HRV) data objectively indicate some bodies' well-being [16]. Even though several research pieces concluded that one could indicate one's perceived stress with HRV measures, it is unknown whether there is a relationship between perceived stress and the measured heart rate variability in this sensor's case. At the start of the research, there is an expected relation between the HRV and perceived stress. When ones perceived stress increases, the HRV drops.

5.1 Method

Design. The study used a repeated-measures experimental design to investigate the relationship between perceived stress level and measured heart rate variability. The measurement ran for every participant for two weeks, thus ten workdays. Perceived stress levels were measured via a self-reported stress scale [17]. The questionnaire was accessible through an online-platform accessible through both desktop and mobile. Heart rate variability was measured through the sensor-equipped cushions. An opportunity sample was recruited (N = 16) from the Eindhoven University of Technology and Hang-zhou Bobo. The recruited participants were only required to do full-time work from their (home) office.

Materials. The study used a self-reported question stress scale (Bartenwerfer[17]). Participants rated how they perceived their current stress level on the scale. The questionnaire was accessible through an online platform available on both desktop and mobile. On submitting, the inputted measure (slider fully up, perceived stress = 1.0, slider fully down, perceived stress = 0.0 – linear scale for all positions in between) is sent to a secure database with a timestamp. The heart rate variability is collected automatically by the sensor-equipped cushion and sent to the same secure database with the corre-sponding timestamp of submitting.

Procedure. Every participant received a sensor-equipped cushion at the start of the project, connected to their preferred Wi-Fi network. Participants were advised to work according to their schedule, not influencing any results. After every working block (morning block (8:00–13:00, afternoon block (14:00–18:00), and evening block (19:00–23:00)1), the participants were asked to reflect upon that block of working (plus-minus 3–4 h of work) and indicate their perceived stress level during that working session.

During the research, all participants were monitored. In a custom-designed webpage, the count of every critical measure in the study was calculated daily. If a participant's cushion failed (most often empty battery), they would receive a message to check their cushion. If the participant worked in a particular block but did not submit their per-ceived stress, one received a reminder through their specified platform.

To create a dataset to analyze the relationship between the measured heart rate variability and the perceived stress, all the submitted survey data (N = 220) was pulled from the database, and the mean HRV data was calculated for all data points in a three-hour block before the submitted perceived stress. Obvious errors in the measurements are dropped (HRV error measurement, submission submitted in the morning, etc.). As a result, a total of 180 submissions and measured HRV levels are present in the dataset (N = 180).

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5.2 Statistical Analysis

Linear regression was run to understand submitted perceived stress on measured heart rate variability. A scatterplot of perceived stress and heart rate variability was plotted to assess linearity. Visual inspection of the plots indicated a slight linear relationship between the variables. Residuals were independent, as assessed by a Durbin-Watson statistic of 1.589. There was heteroscedasticity evaluated by visual inspection of a plot of standardized residuals versus standardized predicted values. The data was square transformed to remove heteroscedasticity. After visual inspection, homoscedasticity and Residuals were normally distributed as assessed by visual inspection of a normal probability plot. One outlier was detected with a Casewise diagnostics test. It was decided not to remove the datapoint as it seemed like a genuine datapoint (Fig. 8).

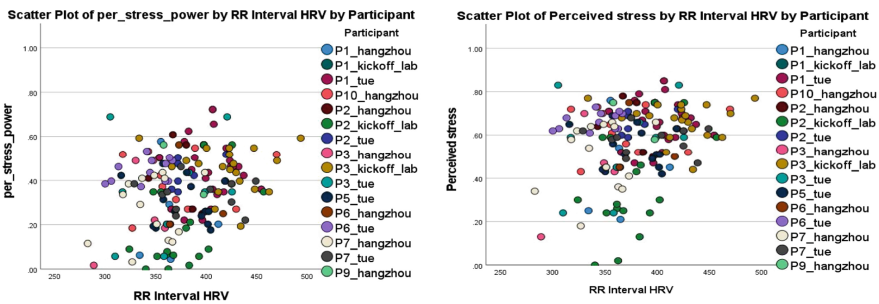

Fig. 8. *left* - Non-transformed perceived stress plotted against the measured mean HRV of a 3-h window. Heteroscedasticity is visually identified. *right* - (perceived stress)^2 plotted against the measured mean HRV of a 3-h window—slight linear relationship between variables present. Homoscedacity visually identified.

The measured HRV statistically significantly predicted the perceived stress, $F(1, 177) = 11.07$, $p < .002$, accounting for 5.89% of the variation in perceived stress with adjusted $R2 = 5{,}45\%$. An extra point on the scale of HRV leads to a 0.001020 increase in perceived stress. Predictions were made to determine perceived stress levels for people with their measured HRV (Fig. 9); please refer to Table 1 for results. The equation to predict the perceived stress with the measured HRV is:

$$\sqrt{}\,(\text{perceived stress}) = -0.02302 + 0.001020 * \text{measured hrv} \tag{1}$$

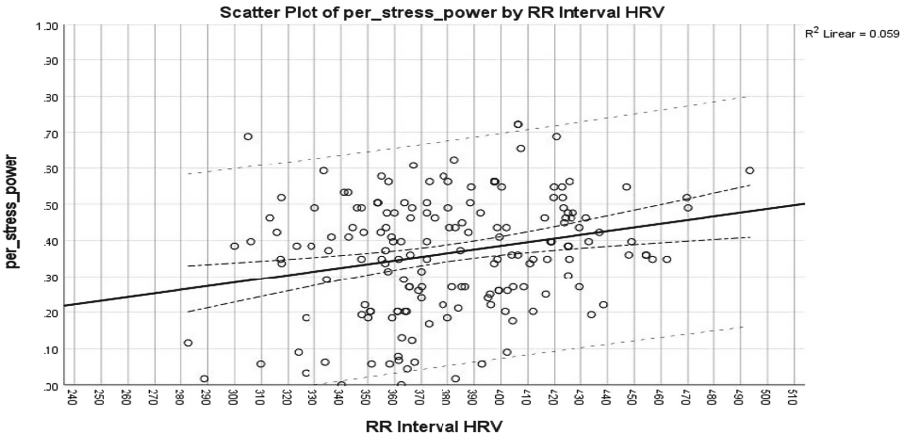

Fig. 9. Linear regression scatterplot. Measured HRV against (perceived stress)^2. 95% Confidence interval plotted, with upper and lower bound.

Table 1. Predictions of (perceived_stress)^2 - calculation of perceived stress - with confidence interval of perceived stress

HRV	(Perceived stress)^2	Perceived stress	Lower bound	Upper bound
350	0.33	0.58	0.55	0.60
375	0.36	0.60	0.58	0.62
400	0.39	0.62	0.60	0.64
425	0.41	0.64	0.61	0.67
450	0.44	0.66	0.62	0.70
475	0.46	0.68	0.63	0.72

5.3 Discussion

The study hypothesized that there is a relation between HRV and perceived stress. When the measured HRV increases, the perceived stress lowers. While the linear regression statistically predicted the perceived stress, the prediction equation contradicts the research's set experimental hypothesis as the relationship is inversed. These findings do not correspond with well-known facts about the HRV. If one HRV decreases, their perceived stress should decrease [16, 18–20]. There has not been any research that validates or explains such an outcome.

Therefore, there is concluded that there is a probable cause for the above result. The participant group is probably too small, and there might have been a confounding variable, resulting in anomalous results. In the future, the research can be rerun to investigate whether the small sample group ($N = 16$) is the problem. Otherwise, there can be concluded that measured HRV is too personal to find a generalized rule. Thus, it is advised to look at trends in the users' data to detect any negative or positive trend in the measured HRV and inform users based on the trend prediction.

6 Discussion and Conclusion

6.1 Collective Versus Individual Visualization

As already mentioned, it seems that it is currently not yet desired to show the collective ones' data (while anonymized, it might still be possible to identify somebody). Both in the user validation of the collective visualization and the interview, it was mentioned that trust and culture are essential in visualizing such data. Therefore, it might be a direction to further explore creating a more open environment between individuals to reflect on their collective stress. In addition, there is indicated in other research that researching hierarchy is essential when designing stress visualizations for the collective [1], and thus, implications of hierarchy should be researched more in-depth.

Additionally, the consequences of COVID-19 on collective visualizations are explored, but other directions can be explored beyond an online call or webpage. As social contact might be more scarce as more and more people are working at home, it might mean that collective visualizations should adapt and support in creating meaningful reflective moments on the collective stress.

6.2 Measured HRV Versus Real-Life Perceived Stress

As already indicated, a correlation was found between the perceived stress and the measured HRV. This correlation was inversed and not according to the hypothesis set at the start of the research.

As the measured HRV is one of the most valuable parts of the sensor, one could extend upon the research done in this project and see whether there are any other methods to give employees an indication of their fatigue levels. Firstly, as already indicated, one can look at the data trends. If data trends down, one can suggest that an employee might feel more fatigued. Secondly, one can extend the research already done. Several methods exist to adjust or create stress status by, for example, a first-person shooter game [21] or a memory card game [22]. Therefore, we can change participants' stress levels, forcing participants' HRV to go down. One could research whether data can be grouped by certain induced stress levels. If so, a generalized rule can be created.

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References

1. Xue, M.: AffectiveViz: designing collective stress related visualization (2021)
2. Brennan, A., Chugh, J.S., Kline, T.: Traditional versus open office design: a longitudinal field study. Environ. Behav. **34**(3), 279–299 (2002). https://doi.org/10.1177/0013916502034003001
3. Leder, S., Newsham, G.R., Veitch, J.A., Mancini, S., Charles, K.E.: Effects of office environment on employee satisfaction: a new analysis. Build. Res. Inf. **44**(1), 34–50 (2016). https://doi.org/10.1080/09613218.2014.1003176
4. Papagiannidis, S., Marikyan, D.: Smart offices: a productivity and well-being perspective. Int. J. Inf. Manag.**51(**October) 0–1 (2020). https://doi.org/10.1016/j.ijinfomgt.2019.10.012
5. Yu, B., Zhang, B., An, A., Xu, L., Xue, M., Hu, J.: An unobtrusive stress recognition system for the smart office. In: Proceedings of the Annual International Conference of the IEEE Engineering in Medicine and Biology Society, EMBS, pp. 1326–1329 (2019). https://doi.org/10.1109/EMBC.2019.8856597
6. Ali, S.M., Gupta, N., Nayak, G.K., Lenka, R.K.: Big data visualization: tools and challenges. In: Proceedings of the 2016 2nd International Conference on Contemporary Computing and Informatics, IC3I 2016, pp. 656–660 (2016). https://doi.org/10.1109/IC3I.2016.7918044
7. Snyder, J., et al.: MoodLight: exploring personal and social implications of ambient display of biosensor data. In: CSCW 2015 - Proceedings of the 2015 ACM International Conference on Computer-Supported Cooperative Work and Social Computing, pp. 143–153 (2015). https://doi.org/10.1145/2675133.2675191
8. Feijs, L., Langereis, G., van Boxtel, G.: Designing for heart rate and breathing movements. In: Proceedings of the 6th International Workshop on DeSForM 2010, pp. 57–67 (2010)
9. Ren, X., Yu, B., Lu, Y., Zhang, B., Hu, J., Brombacher, A.: LightSit: an unobtrusive health-promoting system for relaxation and fitness microbreaks at work. Sensors (Switzerland) **19(**9) (2019). https://doi.org/10.3390/s19092162
10. Li, I.: Designing personal informatics applications and tools that facilitate monitoring of behaviors. Uist (2009). http://www.ianli.org/publications/2009-ianli-uist-designing-personal-informatics.pdf
11. Xue, M., Liang, R.-H., Hu, J., Feijs, L.: ClockViz: designing public visualization for coping with collective stress in teamwork. In: Proceedings of the Conference on Design and Semantics of Form and Movement - Sense and Sensitivity, DeSForM 2017 (2017). https://doi.org/10.5772/intechopen.71220
12. Xue, M., Liang, R.H., Yu, B., Funk, M., Hu, J., Feijs, L.: Affective wall: designing collective stress-related physiological data visualization for reflection. IEEE Access **7**, 131289–131303 (2019). https://doi.org/10.1109/ACCESS.2019.2940866
13. Boland, B., de Smet, A., Palter, R., Sanghvi, A.: The pandemic has forced the adoption of new ways of working. Organizations must reimagine their work and the role of offices in creating safe, productive, and enjoyable jobs and lives for employees (2020)
14. Cohen, R.A.: Yerkes–Dodson Law. In: Encyclopedia of Clinical Neuropsychology, pp. 2737–2738. Springer, New York (2011). https://doi.org/10.1007/978-0-387-79948-3_1340
15. Braun, V., Clarke, V.: Using thematic analysis in psychology. Qual. Res. Psychol. **3**(2), 77–101 (2006). https://doi.org/10.1191/1478088706qp063oa

16. Campos, M.: Heart Rate Variability: A New Way to Track Well-Being - Harvard Health Blog - Harvard Health Publishing (2017). https://www.health.harvard.edu/blog/heart-rate-variability-new-way-track-well-2017112212789. Accessed 2 Jan 2021)
17. Bartenwerfer, H.: Einige praktische konsequenzen der aktivierungstheorie. Zeitschrift für experimentelle und angewandte Psychologie **16**, 195–222 (1969)
18. Harvard Medical School: How's Your Heart Rate And Why It Matters? Hardvard Health Publishing (2020). https://www.health.harvard.edu/heart-health/hows-your-heart-rate-and-why-it-matters. Accessed 16 May 2020
19. McDuff, D., Gontarek, S., Picard, R.: Remote measurement of cognitive stress via heart rate variability. In: 2014 36th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, EMBC 2014, pp. 2957–2960, November 2014. https://doi.org/10.1109/EMBC.2014.6944243
20. Taelman, J., Vandeput, S., Spaepen, A., van Huffel, S.: Influence of mental stress on heart rate and heart rate variability. IFMBE Proc. **22**, 1366–1369 (2008). https://doi.org/10.1007/978-3-540-89208-3_324
21. Bouchard, S., Bernier, F., Boivin, É., Morin, B., Robillard, G.: Using biofeedback while immersed in a stressful videogame increases the effectiveness of stress management skills in soldiers. PLoS ONE **7**(4), e36169 (2012). https://doi.org/10.1371/journal.pone.0036169
22. Admon, R., et al.: Imbalanced neural responsivity to risk and reward indicates stress vulnerability in humans. Cereb. Cortex **23**(1), 28–35 (2013). https://doi.org/10.1093/cercor/bhr369