ONEDERGRANT RESEARCH FINDINGS | 02.26.2021

PUTTING THE PERSON IN PERSON-CENTERED DESIGN

CORRELATING STRESS AND PLACE TO INFORM DESIGN

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OVERVIEW

Keywords: Wellbeing, Stress, Distributed Work, Technology Integration, Human-Environment Interaction

While person-centered design aims to optimize human outcomes through the design of the environment, a challenge is how to measure person-environment interactions to evaluate impacts of the environment on human outcomes. In terms of stress impacts specifically, researchers have historically relied on self-reports of stress from building users to understand stress-place interactions. For example, stories shared in focus groups have helped us understand anecdotally where stress points occur along a journey; however, we have not been able to benchmark those stress moments nor understand how design solutions have quantitatively increased or decreased stress. Having access to physiological stress data linked with place would support the design of spaces and processes which reduce stress or support building users during stressful moments.

The primary aim of this project was to develop a mechanism for correlating stress, location, and activity data, and to visualize this layered data as a journey map, or Moodmap. To demonstrate proof of concept, we set up a pilot study evaluating office worker stress under work-from-home and office workplace conditions. To measure stress, office workers wore devices collecting electrodermal activity (EDA) which has been shown to be one of the most direct ways to measure stress response (Boucsein 2012). Location was tracked using Bluetooth low energy (BLE) beacons and sensors. Activity data was collected using experience sampling surveys sent to a worker's mobile device. We used time-stamping to layer stress, location, and activity data in a database to evaluate potential interactions.

Studies on work-from-home preferences over the past pandemic year have suggested future post-pandemic workplaces will include multiple workplace locations, not limited to exclusively home or exclusively office (Steelcase 2021, Wahi et al 2020). Results captured in our pilot study support these existing studies by providing descriptive trends suggesting that because stress response seems to be linked with aspects of place and activity, flexibility in work locations can best support diversity across activity and individual needs. Given the small sample size of our pilot study, our findings are not generalizable; however, they provide data to inform hypotheses for a larger study.

Ultimately, this study supports Moodmapping as an effective means to evaluate physiological stress points along a person's journey through an environment. As a next step, we will deploy Moodmapping to evaluate stress points in a patient journey at a healthcare facility, and use this data to drive decision making for design and process improvement.

ABOUT BOULDER ASSOCIATES

Boulder Associates is a design and consulting firm that specializes in healthcare and senior living. Founded in 1983, they help clients set new standards for healing environments by aligning facility investments with business strategies and goals. With offices in Colorado, California, Texas, Arizona and North Carolina, Boulder Associates maintains a staff of architects, interior designers, and graphic designers who all share a belief in the power of design to enrich lives. An in-house project consulting group, BAScience, supports clients using science-informed research, lean and sustainability practices.

OUR TEAM

Meredith Banasiak is Director of Research for Boulder Associates Architects. Her first psychophysiology studies were conducted in her role as Human Behavior faculty in the Environmental Design Program at University of Colorado in 2013 when instruments were both expensive and hard-wired! She now makes use of health consumer wearables to conduct research in practice to inform design. As Director of Research, she is responsible for developing research partnerships with healthcare organizations, exploring novel methods for conducting real-time research, and gathering and translating evidence with designers. Meredith serves on the Advisory Council for the Academy of Neuroscience for Architecture, is a Fellow with the Centre for Conscious Design, and has published in psychology, medicine, and architectural research journals and books.

Jenny Hastings is a Principal and licensed interior designer, practicing out of Boulder Associates Architects' Sacramento office. She is a LEED-Accredited Professional and is an Evidence-Based Design and Certification (EDAC) certificate holder. Jenny helped develop Boulder Associates' evidence-based design entity, "Examine", growing the firm's focus on informed design and strengthening client relationships through evidence-based design practices. She is also passionate about patient-centered design and ensuring patients and their families are the focus of design efforts within the firm. Jenny also sits on Boulder Associates' Board of Directors and the firm's Strategic Planning Committee, which allows her to play a key role in helping shape the direction of the future of the firm.

Michael Zabritski is a Senior Associate and Director of Practice Technology for Boulder Associates Architects. He is responsible for employing and innovating building information modeling, computational design, visualization technology, and data analysis workflows and tools, and has spoken about implementing technology in the design process at several design conferences. Michael believes in using the correct tool at the proper time to help clients and project teams make informed decisions. In working with other firm directors, Michael oversees the standardization and

continual improvement of all technology-based project processes. Michael also sits on several Boulder Associates committees to ensure that the firm understands and leverages the rapidly changing technology in the industry.

ACKNOWLEDGMENTS

WE ACKNOWLEDGE THOSE WHO PROVIDED MEANINGFUL CONTRIBUTIONS TO THIS WORK.
Graham Wallace, One Workplace for coaching and guidance.
Liz Anderson for graphic design.
Romano Nickerson for data visualization direction.
Gina Livingston-Smith for her inspiration and passion for person-centered design.
Boulder Associates study volunteers for their enthusiastic participation and willingness to share their experience.

OUR VISION

Imagine if— We could measure our stress based on the space we are in. We could use this information to understand how the spaces we design increase or decrease a user's stress. And, we could ultimately improve the design of spaces and processes to lower stress and optimize wellbeing.

INTRODUCTION

Our vision was to develop a mechanism for evaluating stress interactions between a person and a space and to use this knowledge to inform our design and process improvement work. To demonstrate proof of concept, we set up a pilot study evaluating office worker stress under work-from-home and office workplace conditions. We collected physiological measures of stress, using a wearable device worn on the finger recording electrodermal activity. We utilized Bluetooth low

energy (BLE) beacons and sensors which identified a person's location within a building. We collected information about activity using experience sampling surveys sent to a participant's mobile device. Through time-stamping, we layered stress, location and activity data in a single database to create a Moodmap.

Our pilot study was conducted using a small sample of own Boulder Associates staff volunteers to examine potential differences in stress between the office workplace and the remote work-from-home setting. Studies evaluating work-from-home preferences over the past pandemic year have suggested future post-pandemic workplaces will include multiple workplace locations, not limited to exclusively home or exclusively office (Steelcase 2021, Wahi et al 2020). An August 2020 study found that in a non-pandemic situation, workers would prefer to work away from the office 2-3 days per week (Lindberg et al 2020). Another study conducted across ten countries, suggests that wellbeing impacts an employee's decision over where to work (Steelcase 2021). In support of these studies, our findings examining stress in work-from-home and office workplace settings suggest that because stress response seems to be linked with aspects of place and activity, flexibility in work locations can best support diversity across activity and individual needs.

While our study results are not generalizable, and warrant a larger controlled experimental study on work locations, we are most excited about using Moodmapping with our healthcare clients to identify stress points along a user's healthcare journey. We believe this innovation will allow us to more accurately understand patient healthcare journeys by measuring stress points, and in turn develop solutions which can quantitatively reduce or better support patient stress.

RESEARCH QUESTIONS

MOODMAP DEVELOPMENT

Q. How can we measure stress in real time and real space to improve the design of environments and operations?

PILOT STUDY

Q. Is there a difference in worker stress between office workplace and remote work-from-home environments? Is there a difference between perceived and physiological stress?

OBJECTIVES

Our overarching aim was to develop a mechanism for correlating stress, location, and activity data.

To demonstrate proof of concept, we developed a pilot study collecting data on worker stress, activity, and workplace interactions. We hypothesized:

- Workers experience less average stress per day and less percent of time above a stress threshold during work hours when working from home compared to the office workplace.
- Workers experience peaks in stress levels when performing specific activities.
- Workers self-reported perception of stress does *not* accurately match their physiological stress measures.

METHODOLOGY

person

A wearable device records a worker's stress throughout the day.

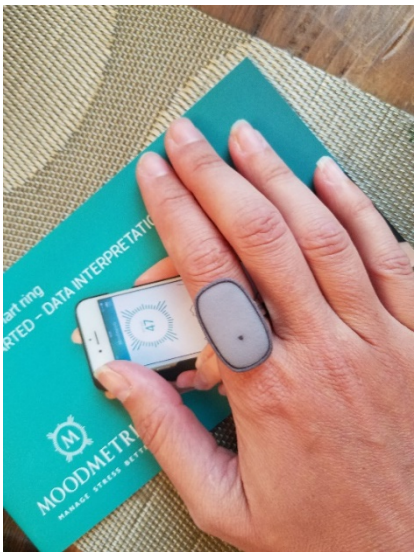
activity

Workers self-report activity using text-based surveys sent to their mobile device throughout the workday.

environment

Bluetooth sensors placed at the worker's home and office settings identify a worker's location.

Wearable devices, location sensors and mobile surveys collect data on occupant stress, location and activity to create layered Moodmaps.



MOODMAP COMPONENTS

Person | Physiological Stress Measures

Physiological stress was recorded using Moodmetric wearable rings. These devices measure electrodermal activity (EDA) through skin conductance and have been shown 83% as accurate as laboratory equipment (Torniainen et al 2015, Pakarinen et al 2019). Changes in a person's skin conductivity occur as the result of sweat gland activity which is controlled by the sympathetic nervous system. Under conditions of stress, the sympathetic nervous system is activated producing physiological

responses such as increased sweat. Thus, electrodermal activity is one of the most direct ways to measure stress response (Boucsein 2012). Stress was recorded as Moodmetric level (MM) using the proprietary index developed by Moodmetric with values from 1 to 100 derived from the electrodermal raw signal which has been correlated with cortisol level (Vigofere Oy/Moodmetric 2020).

Moodmetric daily averages over 24 hours are 50MM (Vigofere Oy/Moodmetric 2020). Since this study only evaluated stress during daytime awake when stress measures are higher than during nighttime sleep hours, 60MM was selected as a threshold for establishing high stress. Average MM for our participant cohort during study collection hours (8:00am – 5:00pm) was 58.7MM. Thus, >60MM represents above an average stress zone for this group under these study conditions.

Electrodermal activity data was first stored in the ring memory and then transferred to the phone app using Bluetooth throughout the day. Timestamped MM levels at a rate of one sample per minute were uploaded from the phone app to cloud storage once per day.

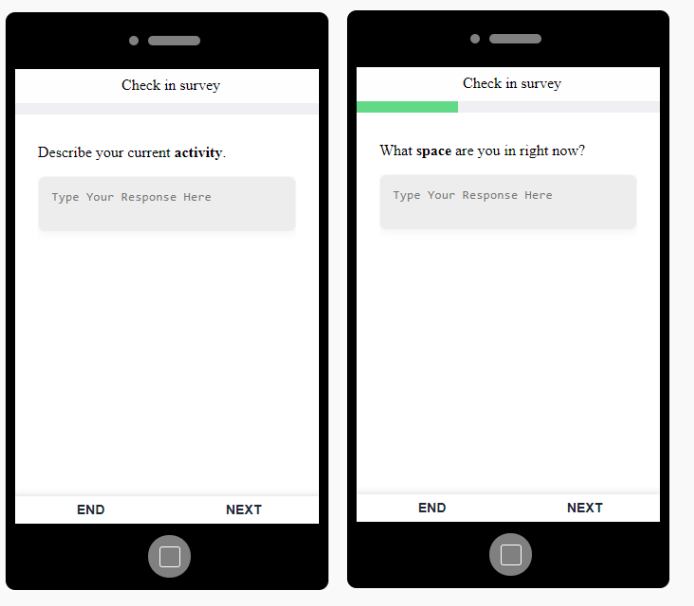
Environment | Location tracking

To create a proximity alert network, proximity sensors in the form of Raspberry Pi computers running Bluetooth low energy (BLE) detection software were located at each participant desk and in the breakroom at the Boulder Associates offices, and at the workspace at each participant's home location. Participants wore a BLE beacon attached to a lanyard around their neck to record proximity to the beacon during study collection hours (8:00am – 5:00pm). When located within range of the sensor (approximately 25ft), timestamped location data was sampled once every minute and uploaded to a cloud database. Location data was averaged to 15-minute intervals during data analysis.

Raspberry Pi computers were built to run Bluetooth low energy (BLE) detection software

BLE beacons were worn by participants and communicated with Raspberry Pi BLE detectors which were located at home and office workstations

Activity identification | Experience sampling mobile surveys



Timestamped activity data was collected using Expiwell's Experience Sampling Methodology (ESM) mobile app. Check-in prompts were delivered to a participant's mobile device five times per day semi-randomly during 90-minute intervals (8:00am – 9:29am, 9:30am – 11:29am, 11:30am – 1:29pm, 1:30pm – 3:29pm, 3:30 – 5:00pm). To ensure participant compliance and remain within the recommended 20-minute per day burden cap (Conner 2015), we limited prompts to six per day (five interval surveys + one end-of-day summary survey) with no more than 3 questions per prompt.

Check-in prompts asked a participant to describe current activity, space location, and perceived stress level on a scale from 1-5 (1 = Not at all, 2 = Slightly, 3 = Moderately, 4 = Very, 5 = Extremely). Participants were invited, but not required, to submit activity reports at any time throughout the study to record activities which occurred outside of the check-in prompts. End-of-day surveys were open during 4:00pm – 6:00pm each day for participants to report work location (100% home, 100% office, and other) to validate beacon tracking and account for work locations such as site visits which occurred outside of the home and office settings. The number of discrete prompt records ranged from 23 – 50 per participant over the 5-day collection period.

Participants received supply packs including rings, sensors and beacons.

PILOT STUDY

Study participants

Boulder Associates employees were sent an email invitation to voluntarily participate in the study during one of two week-long collection periods. Due to the number of rings available, we were limited to 4 participants per collection period, for a total of 8 participants. Participants were selected based on their availability to work at least 20% time at the office workplace setting, and 20% time at work-from-home setting during the weeklong study period. One participant was eliminated from the study for not being able to meet the required location criteria during the collection period. Thus, the total sample size included 7 participants. Participants were asked to keep their mobile device with them throughout the workday hours for location tracking and to receive experience sampling surveys. To protect participant identity, participants were assigned a unique participant number for the purpose of collating stress, location, and activity data.

Duration

Stress, activity, and location data were collected during wake but not sleep hours over a 5-day work week, Monday through Friday, between 8:00am and 5:00pm during two collection periods. Participants were instructed to start wearing the ring for a >12-hour calibration beginning Sunday afternoon overnight through Monday to establish a baseline electrodermal response. This Sunday afternoon - Monday 8:00am data was used to calibrate the ring, but was not used in data analysis.

- **Collection period 1:** October 26 – October 30, 2020, Boulder Colorado
- **Collection period 2:** December 7-11, 2020, Irvine, California

Study Sites

To avoid potential confound effects of office workplace design and amenities, the study proposed to limit participation to workers at a single Boulder Associates office location. Boulder, Colorado was selected as the study site because it employs the largest number of staff compared to Boulder Associates offices in other cities, and could make recruitment of eight volunteers easier and with more anonymity than recruiting staff in offices with fewer staff. However, after the first collection period ended, and before the second collection period opened, the Boulder, Colorado office was forced to close due to county pandemic requirements. Thus, Irvine, California was selected as the site for the second collection period.

Of the seven study participants, three were from the Boulder, CO office, and four from the Irvine, CA office. The difference in study sites is acknowledged as a potential confound.

FINDINGS

PILOT STUDY

Data from the three system components-- physiological stress measures, location beacon and sensor data, and survey responses-- were combined into a single spreadsheet linked by timestamps. Findings were analyzed across the participant cohort to identify potential trends, and within participants to describe individual experiences.

1. MONDAYS ARE HARD.

Our findings suggest that having “a case of the Mondays” could be a real thing! Across the five-day work week, average stress levels were highest on Mondays (Figure 1.1). For five of the participants, percent of time over 60 MM during work hours was highest on Monday (Table 1, Figure 1.2). All seven participants showed rather dramatic fluctuation between high stress and low stress days as measured by % of time above 60MM.

Figure 1.1.
Average MM for working hours, 8a-5p, all participants.

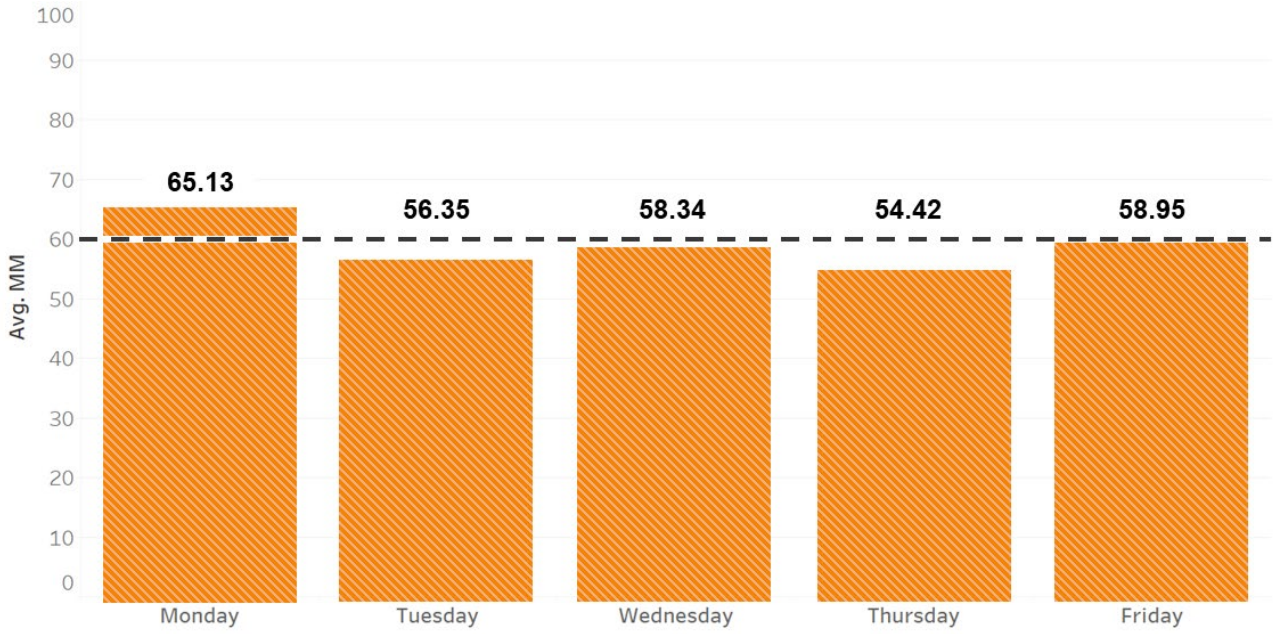
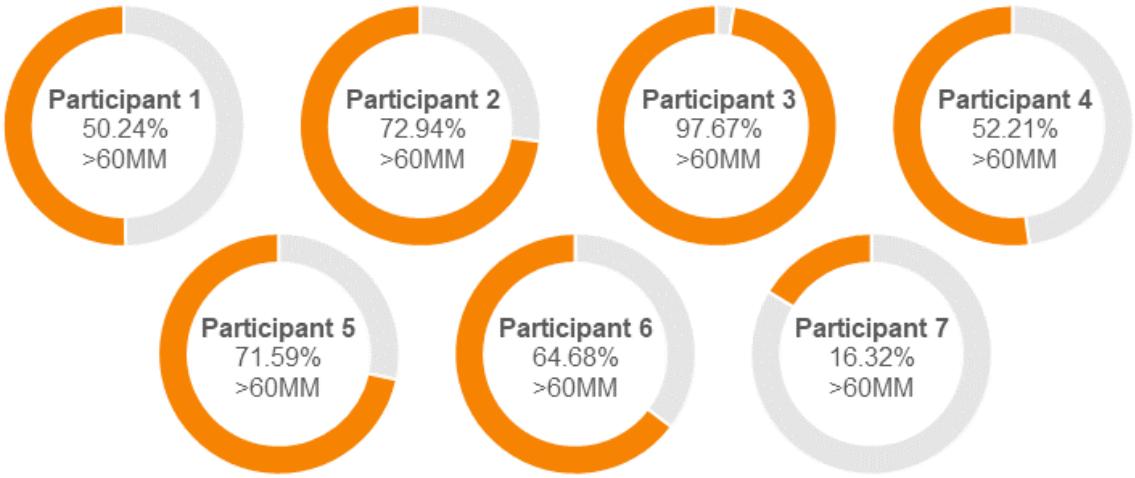


Table 1.
Highest and lowest stress days by % time over 60MM during working hours, 8a-5p.

Participant number	Highest day, % over 60MM	% >60MM, Highest day	Lowest day, % over 60MM	% >60 MM, Lowest day	Difference in % >60MM between Highest and Lowest day
1	Mon	50%	Tues	12%	38%
2	Mon	73%	Thurs	33%	40%
3	Mon	98%	Wed	32%	66%
4	Fri	52%	Thurs	21%	31%
5	Mon	72%	Tues	19%	52%
6	Mon	65%	Fri	33%	31%
7	Tues	46%	Mon	16%	29%

Figure 1.2.
Percent of time above 60MM by participant between 8a and 5p, Mondays.



2. A CHANGE OF SCENERY FROM ONE DAY TO THE NEXT MIGHT DO US GOOD.

Contrary to our hypothesis that workers experience less stress when working remotely from home, we found no evidence that stress was less in a work-from-home setting compared to an office workplace setting. Conversely, trends suggest that stress may be less in an office workplace setting, or perhaps when there is variation in work setting, i.e. when there is a change of scenery, during the

work week. For four of the seven participants, the lowest stress day as measured by MM averaged over 8a – 5p coincided with a > ½ day spent working at the office workplace, and for six of the seven participants their highest stress day measured by % over 60MM coincided with working >1/2 day at home (Table 2).

Since all seven participants spent most of the workweek in the work-from-home setting, with the minority of time spent at the office workplace setting, we cannot deduce that the lower stress experienced in the office setting is correlated with working at the office workplace itself, or if it is an effect of having variation in workplace setting. Future studies should test participants working most of the workweek at the office workplace against a group working most of the time in the work-from-home setting, to better understand if a change of scenery does in fact do us good.

Table 2.
Participant high versus low stress days, and office workplace versus work-from-home setting

Partici-pant #	Highest weekday % over 60MM	Highest AVG MM	Lowest weekday % over 60MM	Lowest AVG MM	Office day, > 5 hours	Home day, > 5 hours	Days with >1 work location
1	Mon	Fri	Tues	Tues	Wed	Mon, Tues, Thurs, Fri	
2	Mon	Mon	Thurs	Tues	Tues, Fri	Mon, Wed, Thurs	Mon, Wed, Fri
3	Mon	Thurs	Wed	Wed	Wed	Mon, Tues, Fri	Thurs
4	Fri	Fri	Thurs	Thurs	Tues, Thurs	Mon, Wed, Fri	
5	Mon	Mon	Tues	Tues	Mon	Tues, Thurs	Mon, Wed, Fri
6	Mon	Mon	Fri	Fri	Thurs	Mon, Wed, Fri	Tues, Wed
7	Tues	Tues	Mon	Mon	Mon	Tues, Wed, Thurs, Fri	Mon

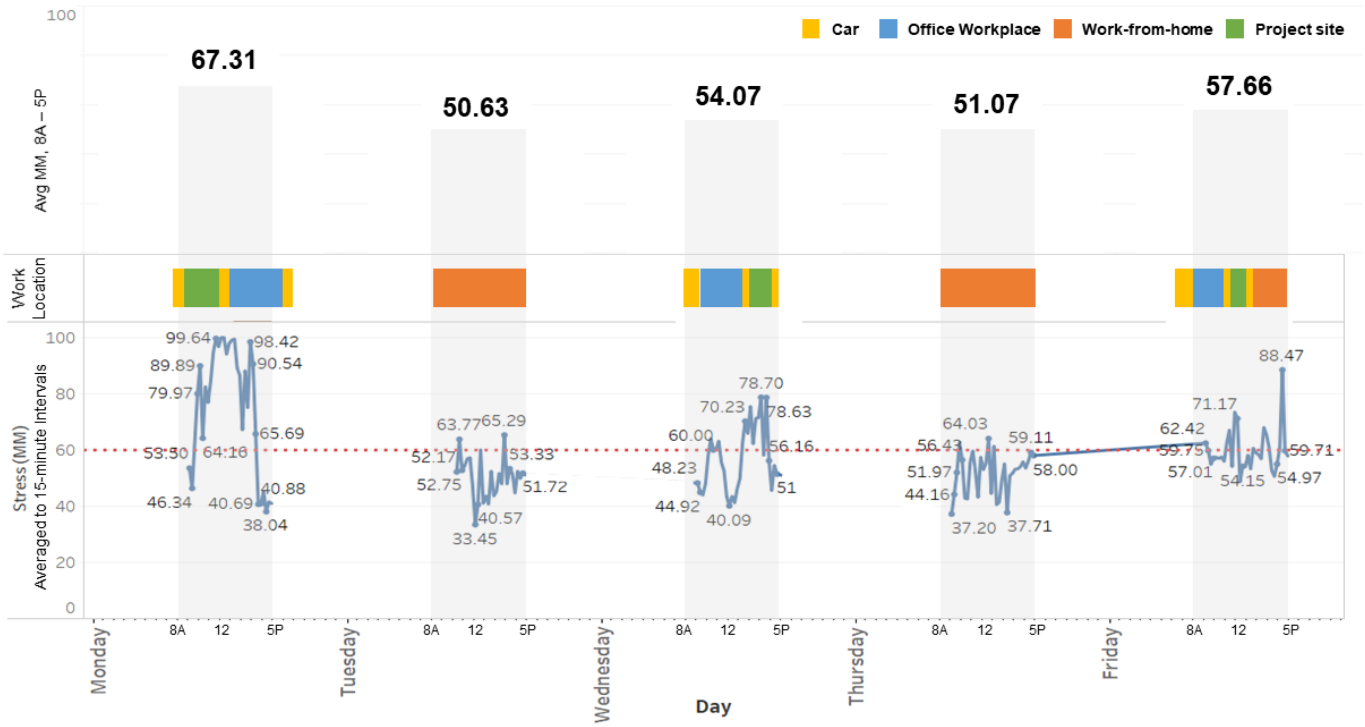
3. TOO MANY PLACES, TOO LITTLE TIME, TOO MUCH STRESS.

While a change of scenery throughout the work week may decrease stress, multiple location changes within a single day may increase stress.

For 10 out of 35 total participant days (7 participants x 5 days/participant), the workday was split among two or three locations. Participant 5's lowest stress days, Tuesday and Thursday, coincided with working from home compared to the other three days which were split among working from home, office, and site visits (Figure 3.1). For this participant, the higher stress experienced on Monday, Wednesday and Friday may be the result of activity (site visits), transitioning between multiple work sites within a single day, or the lower stress experienced on Tuesday and Thursday may be a protective effect of the home workplace location.

Figure 3.1.

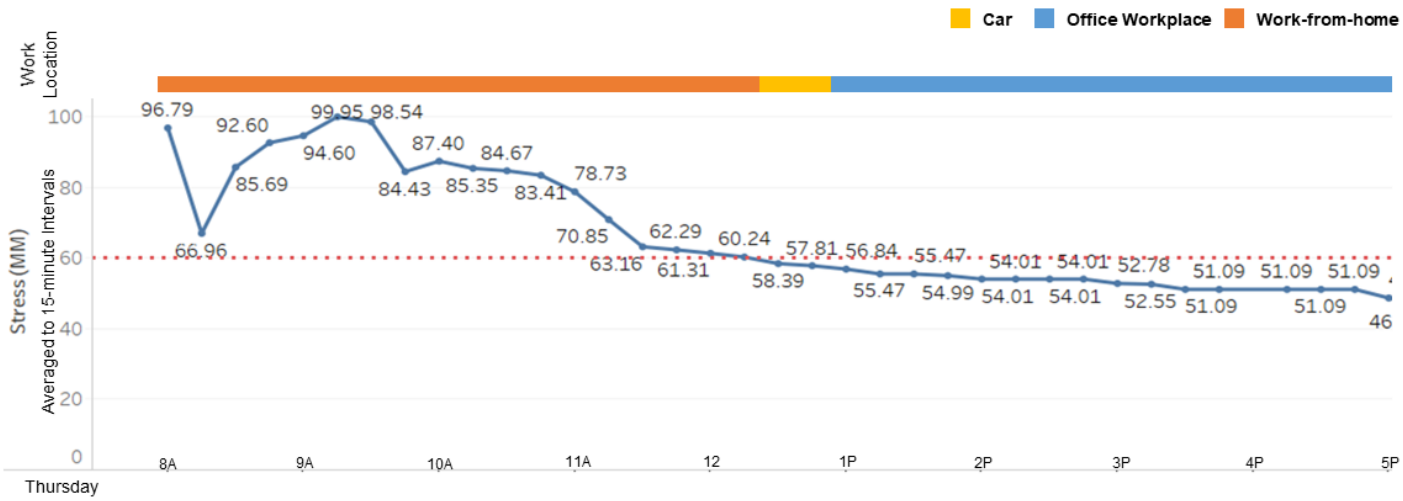
Average MM during working hours, M-F, and work location Participant 5



There was evidence of highly variable stress levels among other participants who changed work location within a single workday. Figure 3.2 illustrates the stress difference when the participant moved from the work-from-home (avg MM = 83.4) to the office workplace (avg MM = 52.9) setting midday.

Figure 3.2

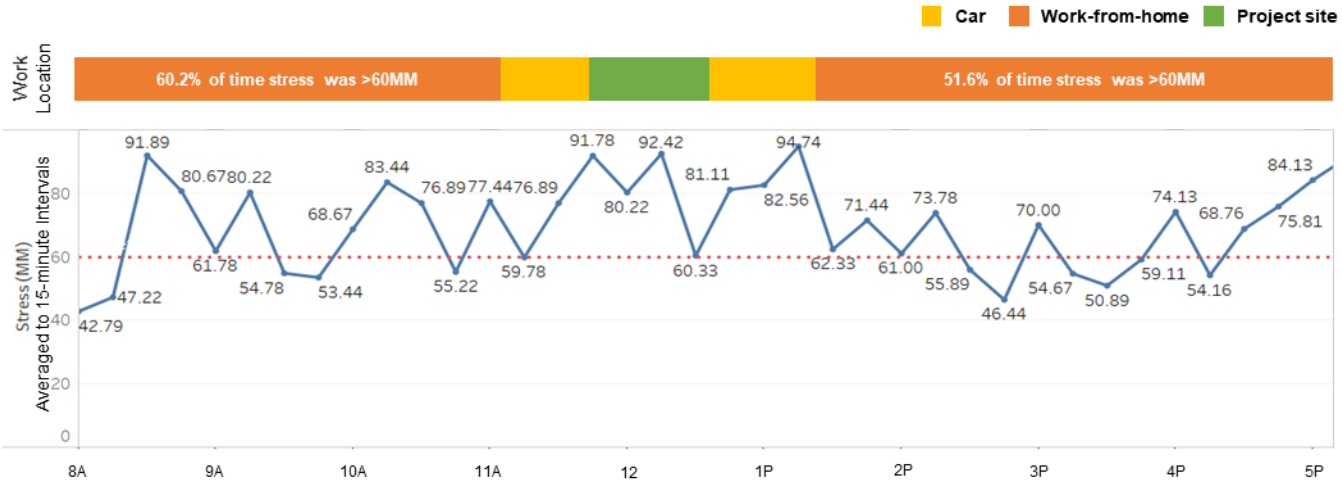
Split workday between home and office workplace locations, Participant 3.



Eight of the ten split location workdays included visits to a project site location. Site visits received the highest stress ratings, perceived and physiological, of the documented work activities (in-person meetings, Figure 4.1). Figure 3.3 shows Participant 2 beginning the workday at home (60.2% of time stress was >60MM), attending a site visit (84% of time stress was >60MM), and returning to the home workplace (51.6% of time stress was over 60MM). For this participant, average stress and % of time above 60MM declined post-site visit even though the setting before and after the site visit (work-from-home) remained the same.

Figure 3.3

Split workday between home workplace and site visit, Participant 2.



These individual instances when considered together suggest that moving work locations, and perhaps even the **anticipation of moving work locations**, within a single day may result in increased stress.

4. PERCEIVED STRESS RELATIONALLY MAPS TO PHYSIOLOGICAL STRESS.

Until this study, we've relied on user self-reports of stress to evaluate relationships between stress, place and activity without a sense of how accurately self-reported stress reflects actual stress. Using survey data from prompts which asked participants to describe current activity and perceived stress level on a scale from 1-5 (1 = Not at all, 2 = Slightly, 3 = Moderately, 4 = Very, 5 = Extremely), we coded each activity using the following key:

 **Driving**

 **Alone work**

 **Virtual meeting**

 **Break during work**

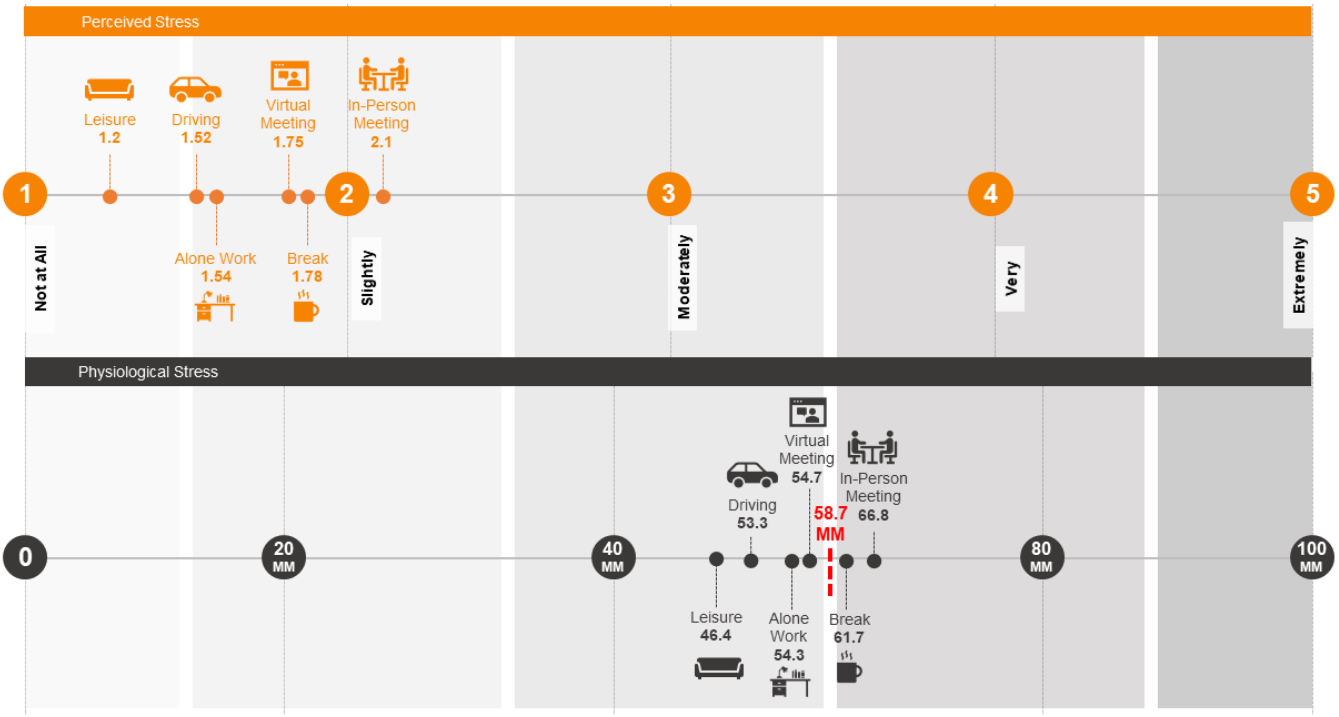
 **In-person meeting (including site meetings)**

 **Leisure (outside of work hours)**

We then averaged perceived stress for each activity type, and physiological stress measures occurring at the corresponding timestamp as the recorded activity, across all participants. We found that relationally, the activities followed the same order from lowest to highest stress: Leisure, Alone work, Virtual meeting, Break, Driving, In-person meeting (Figure 4.1).

Figure 4.1

Average perceived and physiological stress by activity



While the scales for perceived and physiological stress are different and therefore cannot be equivalently compared, it seems that users underestimated perceived stress values relative to physiological stress. Of the 223 total survey data points collected across all participants reporting perceived stress, “5-Extremely” was never selected, and “4-Very” was only selected 2 times (0.9% of the total).

5. STRESS IS LINKED ACTIVITY TYPE.

We hypothesized that workers experience peaks in stress levels when performing specific activities. Our data supports this hypothesis; however, had we hypothesized *which* activities increase stress, we would have been wrong. Driving, which we might have assumed to be among the most stressful activity types, was the second lowest stressful activity according to self-report scores and MM levels (Figure 4.1). The average MM across all participants, all days, during working hours, 8a – 5p was 58.7MM, as shown by the red dotted line in Figure 4.1. Breaks during work, which we might have projected would decrease stress, fell above the average stress threshold, as the second highest stressful activity according to averaged self-report scores and MM levels (Figure 4.1).

In-person meetings were the most stressful activities according to averaged self-report scores and MM levels. Two-thirds of in-person meeting activities occurred during site visits. As suggested by individual data in Figures 3.1 and 3.3, site visit meetings seem to be concurrent with the highest recorded stress measures for participants. This stress increase may be the result of the site-related activity itself, the change in location between work settings, and/or stress associated with concerns over increased COVID-19 exposure risk associated with in-person meetings.

INTRODUCING THE MOODMAP

We used Tableau to layer activity, stress and location data into a single dashboard to track a worker's journey over a given workday. Figures 6.1 and 6.2 depict Moodmaps for an individual worker's work-from-home and office workplace daily journey, respectively. While gaps in activities exist in these examples, future Moodmaps with additional activity data will allow us to quickly evaluate potential relationships among stress, location and activity.

Future efforts aim to layer additional data streams such as environmental variables, e.g., light levels, as well as more seamlessly compare aggregated data from multi-user journeys, and multiple single user journeys.

Figure 6.1

Office Workplace Moodmap, Participant 4

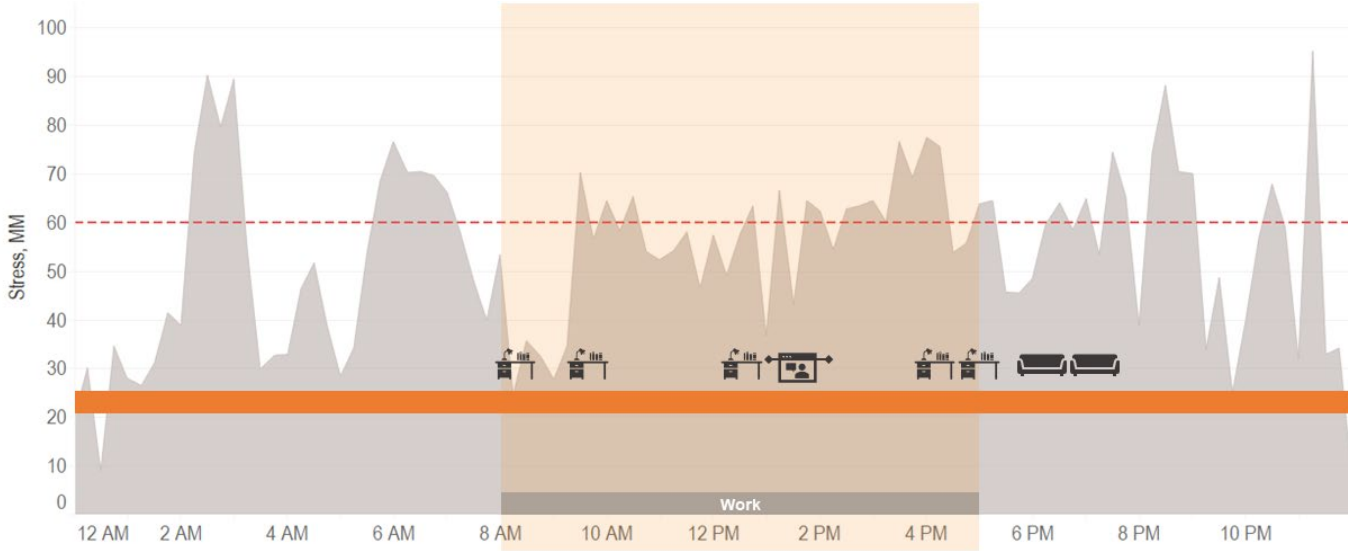
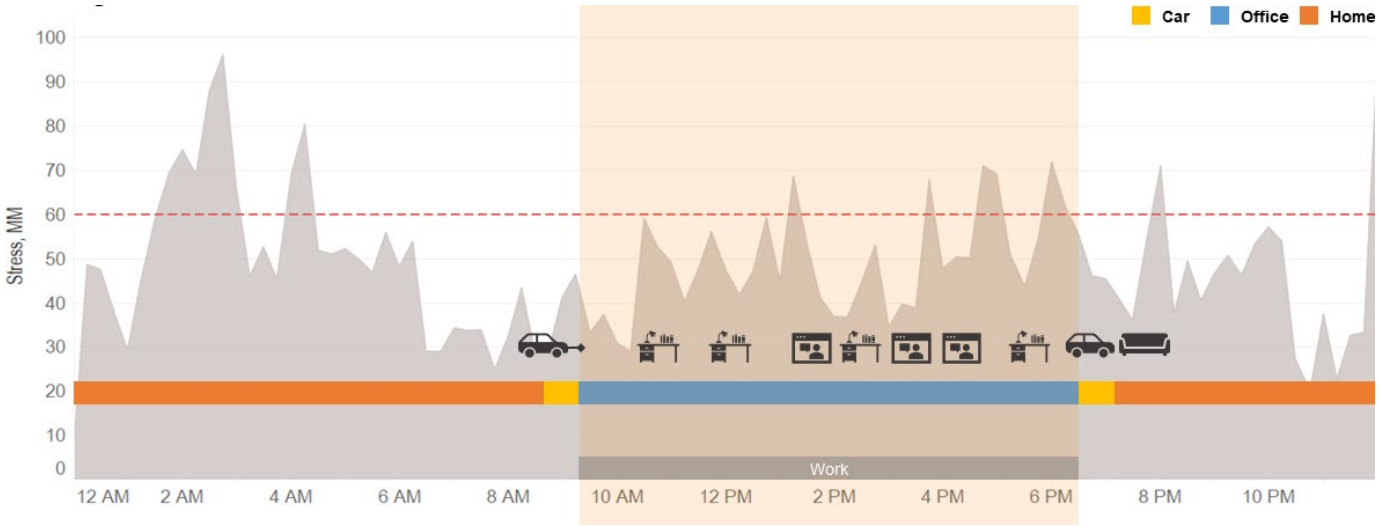


Figure 6.2

Work-from-home Moodmap, Participant 4



LIMITATIONS

Given the small sample size (n=7), cohort trends are not statistically significant, and findings are not generalizable. Instead, descriptive trends provide data to inform hypotheses for a larger study. This study did not account for the many variables which have known impacts on stress such as personality (introversion/extroversion/neuroticism); commute times and traffic conditions; family, child(ren) or roommate distractions in the work-from-home setting; generational preferences; conditions linked with socioeconomic status such as quality and size of the home workplace; and unmet social needs from workers who live alone, among others. We recognize the role that all such variables play in understanding the interaction of stress and workplace setting.

In addition, our pilot study only analyzed physiological stress measures during working hours. Future research studies should collect stress measures across 24-hours to better understand recovery from daytime stress during sleep.

CONCLUDING THOUGHTS

PLACE MATTERS. PLACE IMPACTS STRESS.

All seven participants in our pilot study showed rather dramatic fluctuation between high stress and low stress days as measured by % of time above 60MM (Table 1). Our study findings suggest that

these stress fluctuations may occur in response to changes in workplace location and activity. However, it is not clear that stress is linked with a specific work setting, i.e. an office workplace or a work-from-home setting. Rather, stress response to setting seems variable between individuals and even within individuals. Within individuals, variation in setting itself can potentially impact an individual's stress rather than a specific setting, and moving between locations throughout a workweek, but not within a workday, may be beneficial to reducing stress. Additionally, stress seems to be linked with aspects of place-activity interactions. This finding if confirmed by a larger study, would support the call for flexibility in work locations to best support diversity across activity-based and individual needs.

As mentioned, our descriptive findings are not generalizable and therefore do not yield a set of evidence-based applications, but rather a set of revised, data-informed hypotheses for a larger study. These revised hypotheses are:

1. Mondays are hard. Workers experience peaks in stress levels on Mondays.
2. A change of scenery from one day to the next might do us good. Workers experience lower stress levels when they vary work location throughout the week.
3. Too many places, too little time, too much stress. Workers experience higher stress levels when they change work locations during a single day.
4. Perceived stress relationally maps to physiological stress. Workers' self-reported stress relationally maps to physiological stress measures.
5. Stress is linked to activity type. Workers experience peaks in stress levels during in-person meetings. Workers experience lower stress during alone work activities.

COMING SOON: MOODMAPPING HEALTH CONSUMER JOURNEYS

In the same way we created Moodmaps to depict daily work journeys, we will now deploy this methodology with our healthcare clients to visualize data-driven health consumer and patient journeys. These Moodmaps will be used to identify stress points along a patient journey so that such stress points can be eliminated from the journey, or the environment can be designed in such a way to reduce stress and support patients during stressful moments.

Moving forward, we will simplify the collection components based on the preferences of healthcare clients. Within a traditional patient journey, activity and location typically overlap. For example, a patient is engaged in waiting at the waiting room, having blood drawn at the lab, and having vitals taken at the vital station in a clinic. Thus, we can eliminate either ESM activity surveys, to minimize interruptions along the journey, or sensors and beacons to avoid tech-security issues and infrastructure setup within healthcare facilities.

This report marks not the close of a project, but rather the beginning of an innovative approach for evaluating person-environment interactions to drive design and process improvement decision making by putting the person in person-centered design.

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