SensorBadge: An Exploratory Study of an Ego-centric Wearable Sensor System for Healthy Office Environments

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ABSTRACT

Sensing technology is increasingly used to collect data about the workplace to provide insights into building performance and work activities. While such systems provide meaningful insights, they are a 'black box' in nature considering people as passive data subjects with no input into the sensing and data collection process. We propose a human-data interaction approach where human workers can opt-in using an ego-centric sensor platform – SensorBadge – that provides tools to collect and inspect personal office data. We describe a field exploration of Sensorbadge to understand the wearability, usability, and usefulness of ego-centric data collection. Our results show that office sensing systems should fit seamlessly in the office routine of individuals, without asking for extra effort or creating conflicts with work patterns. Data should be classified and presented against a frame of reference for comparison and visualized to create understandable and actionable representations with personal control of their office environment.

CCS CONCEPTS

• **Human-centered computing → Mobile devices**; *Empirical studies in ubiquitous and mobile computing*.

KEYWORDS

Wearable sensor badge, Ego-centric data collection, Office Vitality, Human-data interaction

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1 INTRODUCTION

In recent years, the use of sensors in office buildings has increased to optimize the building performance and work activities [32, 46]. These sensors allow us to measure contextual factors (e.g., temperature, humidity, light) but could also be used to better understand working routines at the social and individual levels [3, 17, 33, 49]. However, it is unclear how these sensors benefit the workers themselves in a meaningful way, for instance by supporting and empowering them in adopting healthier working routines and support behavior change toward this [13]. Supporting a sustainable employability of employees, based on good physical and mental health, is crucial in this respect, not least to prevent both absenteeism for personal and economic reasons, and to reduce health care costs [14, 29, 62]. However, current office sensor systems are a 'black box' in nature considering people as passive data subjects with no input into the sensing and data collection process [41, 73]. Data should not only be collected, but actuate individuals to do something, putting the user in the end-loop and let them be part of the data collection and reflect on topics such as privacy management, data transparency and data ownership [4, 61]. The collection of data should therefore provide personal value to the user, placing the user in the center of the data collection where the user can manipulate, analyze and make sense of the data [41]. This includes research areas such as hybrid and active ways of working [13], healthy meetings rooms [12] or work well-being [34]. This raises the question: *how can we make these data streams and collections visible and include the office worker in the loop?*

The collection of data sources and streams can be useful for several purposes related to building management, such as to measure occupancy [39, 50] and energy consumption [32, 46]. Data is measured on several levels such as the environmental level (e.g. noise, lighting, temperature, and air quality [18, 30, 49]), personal level (e.g. physical activity, sedentary behavior [7, 38, 40] and work level (e.g. productivity [8, 56]), which influences the work performance, well-being and overall office vitality of office workers. Studies that combine these data sources have indicated associations between office temperature and physical activity [64], mental health and environmental factors (noise, light and temperature) [47] or computer interaction, heart-, sleep-, and physical activity-related data [75]. Combining several data sources within an artifact could therefore have a bigger effect when improving the productivity and well-being of office workers [63]. While these data sources are currently collected separately in office vitality interventions, current work does not use a combination of these types of data in office interventions [13, 53].

The work location, and with this the office building, of office workers has changed into new, hybrid ways of working. In the past, individuals went to an office, had a fixed desk and a fixed schedule. The traditional way of working has changed into an office environment where the fixed working spots are replaced by

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Figure 1: SensorBadge: Sensor implementation and in context when attached to the belt clip

flex working spaces and time slots [44]. The working environment has even further evolved during the Covid pandemic where the environment has changed into a hybrid setting where people change their conventional office work location to occasionally (or regularly) perform work tasks from a home setting [68]. A considerable number of sensor based office vitality interventions are developed to create healthier and active office environments. However, these interventions are designed for the traditional ways of working with fixed working positions and hours, developed solely for the office environment and working hours [43, 69]. Additionally, an individualized working pattern is becoming more common where companies have implemented flexible working hours, where individuals can schedule their work hours based on their work-life balance [44]. These stationary sensing artifacts miss the flexibility to move with the user to different work locations (office, home or remote settings) or flexible work hours [44], and therefore give an incomplete picture of the work environment of individuals.

Our paper has two aims: first, to demonstrate how the identified issues can be addressed by presenting SensorBadge (Figure 1), a wearable ego-centric and multi-source sensing system for the measurement of parameters related to Office Vitality. With SensorBadge, we want to give employees information that is normally hidden as a black box within the building, taking a human-data interaction approach were human workers can opt-in using an ego-centric sensor platform. Second, to discuss the benefits and challenges related to the adopted approach by presenting the results of its evaluation in a 2-day exploratory field experiment, with respect to three parameters: wearability, on-body location and data collection. Our results show that, when designing wearable sensor systems, these systems should fit seamlessly in the office routine of individuals, not ask extra effort or create conflicts with the work pattern. Data from these systems should be classified (moving away from graphs and numbers) and use a frame of reference when presented and visualised to create an understandable representation for novice and non-expert users. System feedback should also be actionable (individuals being able to put insights into action) to provide users with personal control of their office environment. The produced knowledge is relevant for the development of design interventions on the timely topic of office vitality and wearable sensor systems.

Additionally, we discuss the use of a design research artifact as a research methodology to investigate the wearability, on body location and data collection of wearable sensor systems for the office environment.

2 RELATED WORK

Our study combines the field of office vitality interventions and sensor systems, taking a ego-centric approach, to improve the work-well being of office workers. Our study therefore examines prior work in the following research areas: (i) office vitality design space, (ii) field of sensor systems and (iii) factors that influence the work-well being.

2.1 Office Vitality Design space

In recent years, the office environment has been increasingly recognized as an opportune setting to improve the health and well-being of individuals [13, 25]. Scientists and professionals from different disciplines have designed a myriad of interventions tailored to this specific context [13]. For instance, the landscape of physical activity interventions in the office environment is currently dominated by smartphone applications (apps) and fitness trackers as the primary medium to support employees in reducing sedentary behaviours [58]. These platforms use a variety of strategies to support people in reaching their objectives, including goal setting, social factors, or rewards [58]. However, with these apps comes display blindness [42] leading to an attention overload through notifications [51]. Huang et al., [25] highlight a dearth of research on interventions using connected devices other than smartphones and see an opportunity in more tangible focused designs developed for users in their context (e.g. the office).

A majority of the non-digital Office Vitality artifacts are being bound to the office (either environment or desk), using a single data source or only considering the working hours of individuals [13]. The exceptions from this are seen in wearable interventions such as Idle Stripes Shirt [20] and Pedilima [37]. The wearable aspects give users the possibility to bring the artifact with them during the day. A recently developed tangible artifact called Rainmaker [55], developed to support individuals working life in the context of their work setting, uses a different approach by taking a hybrid approach in its form. This artifact is developed to function in the new post-Covid, hybrid way of working where individuals work both from home and the office. However, these interventions rely on a single data source, not considering several data sources. An intervention using multiple data sources is seen in Office Agents [56]. This artifact collects work (productivity), environmental (light, sound and air quality) and personal (physical activity) related data. Break-Time Barometer [28] takes an approach where light level, sound, temperature, battery level and humidity (environmental) and break-time (personal) data are combined in the artifact. These artifacts are however bound to the desk or office environment of the user, missing the hybrid option to bring it to other work locations and/or home settings.

2.1.1 Ego-centric Approach in Office Vitality Interventions. The current field around Office Vitality interventions sees a place-centric approach where the artifact is situated around the direct office space (e.g. desk) of individuals [13]. This place-centric approach is seen on both individual and social levels, creating awareness in the periphery of individuals switching between the center and peripheral attention of users. These interventions fall in the action space of individuals where they are accessible for the user to interact with [59]. However, the action space does not move with the user to different work locations. An ego-centric perspective can help here where the person is the reference of interaction with the artifact and its environment [59]. In this way, the artifact stays within the action space of the individual, continuously collecting data throughout the changing environment of users. An example of an artifact taking this approach, not directly designed for the office environment, is SenseBelt [57] which is a belt-worn artifact that supports interaction between people and devices. The ego-centric perspective of this artifact, combined with the wearable aspect, continuously senses data that is relevant for the users. The current Office Vitality design space does not see any of the design characteristics and approaches as described above. The office environment has however seen ubiquitous, ego-centric, computing devices that monitor the users and their environment. SenseCam [22] is developed as a small, hybrid camera that digital records the user’s day, by recording a series of images and capturing sensor data. This system collects information about the user’s environment (photos) based on their environment (changes in light) and personal data (body heat). The development of SenseCam also formed the design requirements for these hybrid, ego-centric artifacrs, where users need to be able to take it on and off, small and light. From a technical perspective, the artifact needs to have a (reasonable) battery lifetime, data storage and recharge possibilities [22]. Similar design requirements are stated in TalkingBadge [19] were, additionally to the power and data storage requirements, requirements are set for power indication and recharge possibilities.

2.2 Current field of Sensor Systems

Several sensor boxes or systems have been developed in the past. PhysiCubes [23] consists of 4 different sensor boxes (light, noise, temperature, humidity, CO, NO2) and corresponding ambient display data visualizations: light, vibrations, movement, or airflow. These sensor boxes are developed as a modular system, using a single sensor, placed within one artifact and location. Another example is the SensorBox of Sakakibara et al., [52]. The SensorBox consists of an environmental sensor (temperature, humidity, atmosphere pressure, vibration, sound, light, and motion) and a hub. The Sensorbox was developed as a stationary system. As a result of their study, Sakakibara et al., see an opportunity to further develop this concept as a mobile type sensor such as a smartphone or wearable device [52].

On a prototyping level, Candanedo and Feldheim [11] developed a sensor system to predict occupancy in the office. In their system, they use light, temperature, humidity, and CO2 sensors to monitor the work environment. The sensor was placed on the desk of the user. On a similar level, Smart Sensor Box [9] uses an accelerometer, temperature, humidity and CO2 sensor to measure the occupancy in the environment. Both these sensor boxes show how low-cost sensors can be used to monitor the work environment. Next to this, van der Valk [63] developed environmental sensor modules to measure variables relevant to the work environment. The modules measure temperature, humidity, light, noise, and motion. They combined their sensor module with a smartwatch to also measure both personal and environmental data.

2.2.1 Ego-centric Approach in Office Sensor Systems. The artifacts presented above show several forms of sensor systems with different kinds of sensors to sense the office environment. These systems take an place-centric approach [59], similar to the earlier mentioned Office Vitality interventions, where these systems are developed as stationary systems. These systems have the disadvantage that they only monitor the environment in a fixed place and therefore lack information about the direct environment of the user [72]. Mobile sensor systems, which take an ego-centric approach, offer a solution here since they measure the immediate surrounding of the user [52]. While these mobile sensor boxes tend to be less accurate due to their changing position, the mobile sensors have the advantage of being low-cost and compact [72]. Within this ego-centric approach, the sensor system moves away from its fixed, stationary position to an ego-centric approach where the user becomes an active sensor. The user will be the center of the data stream taking a Human-Data Interaction approach [41] within the artifact. Based on this approach, the choice is made in this study to develop a ego-centric, hybrid sensor system that provides individuals with insights to improve their office well-being.

2.3 Factors Influencing Work Well-Being

Several personal and environmental factors have been studied on how these influence the work well-being of office workers. These factors are measured with both stationary and wearable systems to measure contextual factors and understand work routines at the social and individual level.

Sound - Sound level (also defined as noise in research) in the office environment influences the work performance of employees [33]. Sound both includes the sound of other people in the surrounding (e.g., people talking, calling) as well as environmental sounds (e.g., keyboards, printers) [27, 49]). High levels of noise lead to a decrease in productivity, concentration, and overall job satisfaction [27, 49]. The use of open office spaces can further increase the sound level in offices due to the increase of communication [15].

Office workers are however more comfortable if they can control the sound/noise to suit their own requirements [49].

Light - Light plays an important role in the office environment and influences the way individuals are working [33]. Exposure to natural light in the office impacts an employee's quality of life and positively affects the work performance, productivity, attendance, and cognitive task performance of individuals [17, 49]. Lack of light will however cause headaches, seasonal affective disorder, and eyestrain [3]. Daylight exposure at work has been linked to improved sleep mood, reduced sleepiness, lower blood pressure, and increased physical activity [3]. Office workers might therefore feel uncomfortable when working in a work environment that does not fit the requirements [49].

Temperature - The temperature in an office environment influences the work performance of employees [33]. An increase in temperature could cause thermal stress, resulting in a decrease in work performance, thinking, and concentrating [2, 33, 49]. When the temperature is however experienced as conformable, an increase in motivation is seen. Different kinds of work tasks may require different temperatures to increase productivity [17]. This highlights the importance of focusing on offices tasks, when determining the temperature of the room an employee is working in and providing individual level thermal control, where possible [3].

Humidity - The humidity in an office environment affects the work performance of individuals. Studies show that low humidity could cause watery eyes, headaches, problems with your airways as well as a decrease in work performance [3, 71]. An increase in the indoor humidity could however positively impact the work performance [71]. Ventilation is one of the key elements to improve the humidity level, which is done by opening windows or air-conditioning [70]. This will however depend on personal preferences. Therefore, personal adjustment of humidity and temperature appears to be a promising area to look into for a satisfactory workplace [71].

Physical (In)Activity – A healthy and physically active work style has been proven to improve the work performance, workability and self-esteem [1, 65, 66] as well as mental health, creativity, increased productivity, stress tolerance, improved decision making and future orientation [21, 74]. It is therefore important for individuals to have the possibility to implement active ways of working in their work style [13]. Several design interventions have been developed to improve physical activity in recent years, focusing on the reduction of sedentary and inactive behavior in the office environment.

Based on the presented work, we see an opportunity in combining data sources, within a ego-centric system that is crafted for the work style of individuals for a productive and healthy office environment. These principles are implemented in SensorBadge. SensorBadge takes an ego-centric, human-data interaction approach where the user becomes an active sensor. The wearable design approach of the badge gives users the possibility to wear it providing users with insights about their office environment during the day. Using a tangible design research artifact deployed in a 2-day field study, we study specifically the wearability, on-body location and data collection of wearable sensor systems.

3 SENSORBADGE

To support a new human-data interaction approach for participatory data collection [41] in hybrid working environments, we developed SensorBadge. SensorBadge takes an ego-centric approach, placing the user in the center of the data collection. The form and functions of the badge are based on the design requirements set by Hutchison [22] and Hansen [19] for badge like artifacts while combining multiple data sources in a hybrid artifact that is adaptable for the job demands of individuals, as defined in the design principles.

3.1 Design Principles

The functions, form and aesthetics of SensorBadge are based on the following design principles:

Use of multiple data sources: SensorBadge collects data from both the user (steps) and the environment (light, sound, temperature and humidity). These types of data have been shown to influence the work well-being of individuals [3, 17, 33, 49]. The movement will also show if the environmental conditions are changing due to a change in environment or the user changing to a different environment. The combination of data will also give insights into potential patterns or trade-offs between the data sources.

Wearable design: SensorBadge gives employees information that is normally hidden as a black box within the building, taking a human-data interaction approach were human workers can opt-in using an ego-centric sensor platform [41, 73]. To create this ego-centric platform, SensorBadge is developed as a wearable badge holder, which is an item regularly used in the office environment and which individuals bring with them throughout their day. The design can be hung on the neck of individuals, attached to a belt, or be taken off and placed on the desk while working. The badge form artifact gives users the possibility to collect data throughout several settings and changing environments.

Design for hybrid working: The current working pattern is changing where time-spatial flexibility is implemented to create a person-job fit where individuals can plan their own healthy and active work patterns [44, 69]. This also includes working in different work locations (both office and home) fitting for different work-related tasks. SensorBadge wearable, ego-centric nature provides individuals with the option to adapt or change their work setting based on their needs or preferences, without having to change sensor system.

Privacy: Sensor systems in the office environment are developed as a "black-box" where the sensing is done without any opt-in possibilities. The user is not part of the data collection and does not have control over topics such as privacy management, data transparency and data ownership [4, 61]. SensorBadge provides users with the option to opt-in. Users can choose if, where and when to wear the artifact, based on their choice, setting and preference and always have option of turn it off. They also have insights into their own collected data, including full transparency and management on the data collection.

Social visibility: SensorBadge is worn on the clothing of office workers. This gives SensorBadge a social visibility where social feedback and support can be provided between individuals [7]. This social feedback could help to start conversation between individuals where the topic of office sensor systems becomes a talking point in the office environment [45]. This social support can help with the social integration and awareness of healthy office environments to improve the well-being of office workers.

3.2 Development of SensorBadge

The design principles were implemented in the design of SensorBadge. These principles were implemented in the (i) form factor, where the ego-centric approach is taken with the badge like design and (ii) technical design, where the technical design facilitates a human-data interaction approach where human workers can opt-in using an ego-centric sensor platform.

3.2.1 Form factor. SensorBadge (Figure 1) was designed as a badge holder to fulfill a second function for the employees to carry it around. A badge holder is an item frequently used in offices to enter rooms, make reservations or get coffee. People bring this item with them throughout their day due to its frequent use. A badge holder is also often worn on the body (e.g. via a key cord or belt chip) and therefore visible to the environment. The same characteristics were included in SensorBadge where people have the option to carry it on them in several ways. The on-body location of SensorBadge also gives the sensors a position where the sensor can measure without being blocked by, for example, clothes (Figure 2). This approach also moves away from the commonly used smartwatches and applications on phones, which are hidden (in pockets, bags or underneath sleeves) and therefore miss the social visibility and can potentially influence the incoming data.

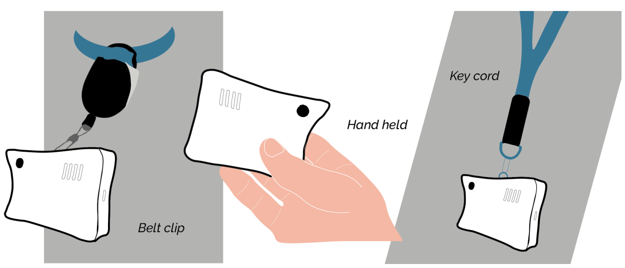

Figure 2: Three usability positions of SensorBadge: (i) belt clip, (ii) hand held and (iii) key cord

SensorBadge's dimensions (95x65x24 mm) make it portable, mobile and easy to move. The badge weights 95 grams and is therefore not a big additional weight for individuals, while moving to a different location. This form shows a new approach in Office Vitality intervention where an existing office artifact is transformed in a new artifact.

3.2.2 Technical Design of SensorBadge. Sensorbadge (Figure 3) is battery-powered by a 2000 mAh battery (5) that can power it for around 36 hours. It uses a TEMP6000[1] (3) to measure the luminous intensity, a DHT22[1] (2) measures the humidity and temperature, a MAX4466[1] (4) board to measure sound, and an MPU6050 accelerometer[1] (6) to measure movement/steps. The sensors are controlled by a Particle Photon[2] (8). All electronics are soldered on a custom-made PCB (7) to minimize the overall size of the electronics. SensorBadge case is created using a 3D printed PLA case. SensorBadge had to be carried around and thus it was important to minimize the size and thickness. With these design characteristics, the design matches the design requirements set by Hogers [22] and Hansen [19] with SensorBadge being small and light, able to take it on and off, having a battery life for over a day (and recharge possibilities), power (12) and WiFi status (11) and having the needed data storage.

Data from SensorBadge is collected and visualised via two servers: Google sheets to collect the data and Adafruit IO[3] dashboard to visualise the data. For the data visualisation, data is sent from the Particle Photon with a time interval of 2 minutes to the Adafruit dashboard, developed for SensorBadge. The dashboard shows the last data point (gauge) and the data of the last 24-hour (graph). This representation of data via a data dashboard is commonly used by data related services such as Fitbit[4] or RescueTime[5]. For the data collection, data is sent to the Particle Cloud and saved in Google Sheets via IFTTT[6] (If This, Then, That). The data is sent as a package and parsed for analysis. The badge is connected to a portable Mifi router, making is possible to always be connected to several work locations (both office and home).

4 METHOD

To evaluate the design characteristics of SensorBadge, we conducted a field study. Participants (N = 7) used SensorBadge for 2 days (2 x 6 hours) while conducting their normal work tasks. The study focuses on three main questions: *(i)* Does the data collected through Sensorbadge provide an accurate characterization of 'Office Vitality' for an individual user while performing office related tasks?, *(ii)* What is the influence of the wearing location of the SensorBadge (belt clip, handheld or key cord) on the data quality and overall usability? and *(iii)* What is the impact of using SensorBadge on everyday activities and tasks?

4.1 Study setup

We deployed SensorBadge in the wild and asked participants to use it as part of their day to day work for a period for 2 days (2 x 6 hours). Every position was experienced by the participants for 4 periods of 1 hour. During the 2 days, participants went through the following phases: *(i)* Introduction and on-boarding of the study, *(ii)* Day 1 with SensorBadge and experience sampling, *(iii)* Debriefing day 1: interview with data dashboard (Figure 4), *(iv)* Day 2 with SensorBadge and experience sampling, *(v)* Debriefing day 2: interview with data dashboard. *(vi)* Exit interview. Participants were asked to reflect on the wearability, use, on-body location and data collection of SensorBadge. Using Experience sampling [35], participants reflected hourly (6 times a day) on their experience via an online survey in Microsoft Forms. The survey asked participants about their current work activity (e.g. working behind desk, meeting, measured via a Likert scale 1-5 Very good to Very poor), state of the work environment (e.g. noise, stress, amount of individuals, possibility to be physically active) and how vital they felt (ranking 1 - 10). The

[1]https://adafruit.com
[2]https://docs.particle.io/photon/
[3]https://io.adafruit.com
[4]https://Fitbit.com
[5]https://Rescuetime.com
[6]https://IFTTT.com

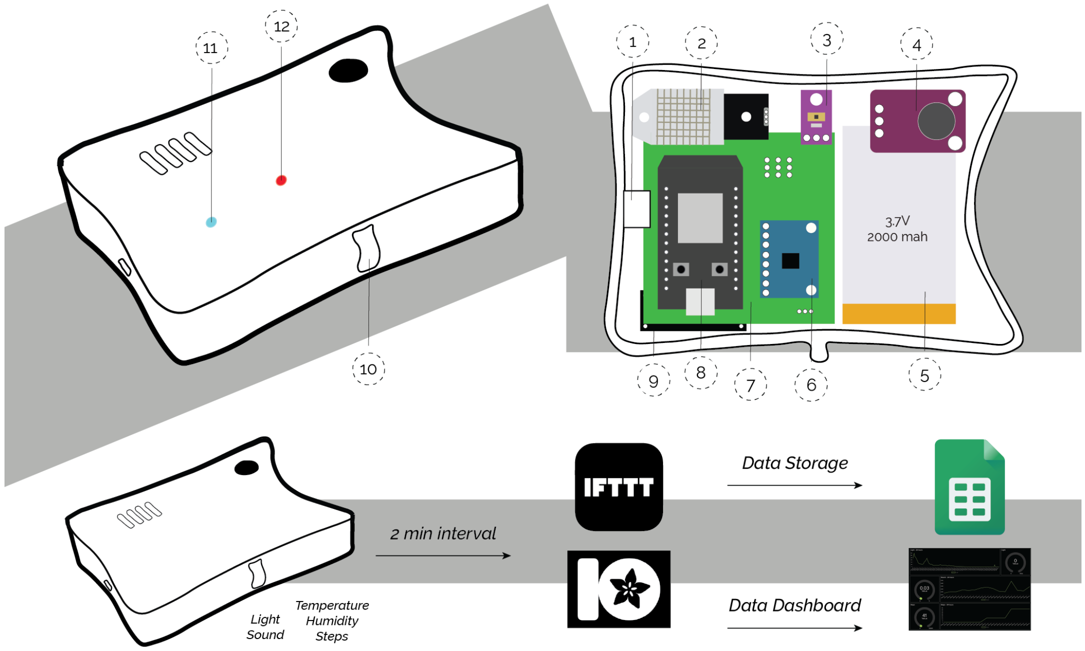

Figure 3: Technical drawing of SensorBadge:(1) female micro USB for charging, (2) DHT22 temperature and humidity sensor, (3) TEMP6000 light sensor, (4) MAX4466 sound sensor, (5) 2000 mah lipo battery, (6) MPU6050 accelerometer, (7) custom made PCB, (8) Particle Photon (9) li-ion charger, (10) key cord/ belt clip holder, (11), Wi-fi connection light, (12) power light

second part of the survey focused on the usability of SensorBadge asking participants to rate (Likert Scale 1-5, Strongly disagree - Strongly agree) the wearability, appropriateness for work activity, on-body location and data collection. After each hour, participants were asked to change the on-body position of SensorBadge (key cord, belt clip or hand held, (Figure 2)). The link for the survey and new position of SensorBadge were sent to participants via email or WhatsApp, depending on the preference of the participant. After each study day, an interview was conducted where participants could further elaborate on their experience with SensorBadge. After each day, the data of SensorBadge was presented to the participants to make them reflect on the data patterns (combined with the answers, provided in the survey questions), regarding their activities and on-body position of the badge. Participants were presented with a data dashboard (Figure 4), similar to the *"Guess the data method"* of Kurze [31], which provides an overview of their work pattern and SensorBadge. The same procedures are followed for the second day. After day 2, an exit interview was held to reflect on the overall experience.

4.2 Procedure and Participants

A mixed-method approach is used, taking a qualitative approach from the interviews (interviews after each day to evaluate the data dashboard and exit interview) and experience sampling and a quantitative approach with the sensor data collection. Participants were contacted via email and a flyer was sent out within the companies for participants willing to join a study on: *"SensorBadge is a device designed to collect environmental and daily activity data to estimate the level of 'office vitality' for an individual. The goal of this study is to investigate the efficacy, feasibility, and usability of SensorBadge in real-world scenarios."*. The nature of this study is a shorter, exploratory study with a smaller sample size [10] to evaluate usability (wearability, on-body location and data collection) in these kind or ego-centric wearable sensor systems. The study takes an ecological valid approach with a large data collection of 2520 data points per sensor (12.600 in total all sensors combined), per participant and 48 experience sampling data points per participant. The field study included 7 individuals (3 female, 4 male, average age of 28.1) working in an office environment (1 research assistant, 2 office managers, 2 interns and 2 PDEng trainee). 5 participants worked in an office setting for all study days, while 2 participants used the SensorBadge in a hybrid setting (1 day at home and 1 day at the office). Participants were interviewed using semi-structured interviews, after each day of using SensorBadge. The data of the interviews were analyzed using Thematic analysis [6].

Semi-structured interviews were conducted with all participants after each day. The interview focused on the following 3 main questions: (i) *Does the data collected through Sensorbadge provide an accurate characterization of 'office vitality' for an individual user while performing office related tasks?*, (ii) *What is the influence of the wearing location of the Sensorbadge (belt, handheld or badge) on the data quality and overall usability?* and (iii) *What is the impact of using Sensorbadge on everyday activities and tasks?* Follow-up questions were asked based on the answers of the participants. The interviews were recorded after receiving the participants' consent, after which they were transcribed and analysed. Based on

Participant Number #P4		Day 1 Hour 1	Day 1 Hour 2	Day 1 Hour 3	Day 1 Hour 4	Day 1 Hour 5	Day 1 Hour 6	Day 2 Hour 1	Day 2 Hour 2	Day 2 Hour 3	Day 2 Hour 4	Day 2 Hour 5	Day 2 Hour 6
Work setting	Current Activity	Working behind desk (reg)	Working behind desk (reg)	Working behind desk (reg) and lunch (break)	Working behind desk (reg)	Working behind desk (reg)	Working behind desk (reg)	Working behind desk (reg)	Working behind desk (reg)	Working behind desk (reg)	Working behind desk (reg)	Working behind desk (reg), lunch break	Working behind desk (reg)
	Ranking work setting (1 very low - 5 very high)												
	Noise	3	2	3	3	3	3	3	3	4	3	3	3
	Stress	4	3	2	2	3	3	3	3	3	3	3	2
	Amount of people	2	2	1	2	2	2	2	2	2	2	4	2
	Productivity	3	4	4	3	3	3	2	3	3	3	3	3
	Possibility to be Active	4	3	3	3	3	3	3	3	3	3	3	3
	Vital ranking (1 - 10)	6	6	6	6	6	6	6	6	6	6	6	6
Experience SensorBadge	Likert scale (1 - 5)												
	Wearability	4	2	4	4	2	4	4	2	4	4	4	2
	Appropiate for work activity	3	3	3	3	2	3	3	3	3	3	3	3
	On-body location	4	2	4	4	2	4	4	2	4	4	4	2
	Correct data	3	3	3	3	3	3	3	3	3	3	3	3
Device position	Hand held, Belt Clip and Key Cord	Hand held	Key cord	Belt clip	Hand held	Key cord	Belt clip	Hand held	Key cord	Belt clip	Hand held	Belt clip	Key cord

Figure 4: Data Dashboard: used to collect the participant data and reflect on during the interviews. The presented dashboard is an example dashboard of a single participant

the analysis, 70 codes were selected. During a second round of coding, the codes combined into 12 themes, which were afterwards merged into 9 overarching themes. Five interviews were held in Dutch, the native language of the participants and two in English. Quotes from the Dutch interviews were translated to English for this paper. Data from the SensorBadge was collected via Google Sheets as a csv. The data was parsed and visualised in the Data dashboard (Figure 4). The data from the experience sample (collected hourly via the Microsoft forms) was inserted manually every hour. With this approach, the survey data, sensor data, badge position and experience, work activities, and setting were matched together.

5 RESULTS

SensorBadge was deployed for 2 days (2 x 6 hours). During this period, participants reflected on the on-body location, wearability and collected data. In this section, we report the experience of the participants based on the (i) interviews, including the data collection and quality and (ii) experience sampling.

5.1 Interviews

Nine overarching themes were defined: wearability, hybrid wearable options, form and social visibility, data sources and additional data, data quality and accuracy, data output and meaning, putting data into action, ego-centric vs place-centric and potential long-term role of SensorBadge.

5.1.1 Wearability. This study focused on the question: *What is the impact of using SensorBadge on everyday activities and tasks?* This study showed that the position of the badge had an impact on the work activities on individuals. SensorBadge was used in 3 positions, hand held, belt clip and key cord. For those 3 positions, the belt clip was commonly (N = 5) seen as the preferred position. This was due to the belt clip position fitting seamlessly in the work pattern of individuals: P2: *“The belt clip because I don’t have to think about that when I get up and walk away”*, P3: *“The belt clip was my favorite position. You just have to click it on and you don’t have to think about it when you walk away”*, P4 *“You don’t have to look at it [at belt clip] so you don’t have to do anything with it, so that is the most convenient”* and P7: *“Yes, the belt clip was the best thing. Because I didn’t need to think about it if I was having it with me. I was just like was the name suggested, it’s just a badge.”*

The hand held position was experienced in a similar, positive way (N = 5), but has the disadvantage that individuals have to consciously have to remind themselves of the device when changing locations: P1: *“I’m pretty sure if I have to hold it [the SensorBadge] in my hands that I would constantly forget to take it with me”*, P2: *“That’s what I had with that hand held the first time, the first time I ran away, I directly forgot about that.”*, P3: *“The hand held is one that you always have to carry, pick up and think about.”* and P4: *“When I put it on the table, I keep forgetting it.”*

Holding the SensorBadge in your hand, also led to the inconvenient situation where individuals had to bring other items with them, and therefore, had problems bringing the badge with them: P1: *“During lunch I have to do all kinds of things, like going to the toilet, getting something to drink and eat and these are actions where I actually need my hands”* P5: *“with hand held I had this a bit, if I had to walk somewhere I would quickly put it in my pocket. I don’t know if that was the intent but...”*, P5: *“Because if you hold it in your hand, you have 1 hand in use and you can’t use it for other things.”* and P6: *“It would however be challenging when walking around because I don’t want to have it in my hand.”*

The third option, the key cord, was experienced as the least favorite option (N = 4). This was indicated due to the key dangling around hitting the table of getting tangled around other objects: P2:

"When I lean back a little and then I again wanted to start typing then it banged [the badge] against the table every time", P3: *"Yes, that was me hitting the table with the badge. At first, I thought this is really nice [key cord] but now, I thought: it's not nice at all to have it around my neck"*, P4: *"Especially the key cord is not really useful. It hangs there a bit and if you then work it bounced against everything."*, P5: *"The key cord was a bit more annoying because it was the whole time bumping into the table or lying on your lap."* and P6: *"I think that was a meeting where I had to, I had my headphones on and just wearing the thing [Sensorbadge] gave some issues because it was tangled, but that was not a general thing."*

5.1.2 Hybrid Wearable Options. Because of the experienced limitations of singular 3 positions, participants opted for hybrid options where positions are combined. The most common hybrid option was indicated as a combination of hand held and belt clip (N = 4). This combination has the benefit of wearing the SensorBadge with you when moving to a different location while placing the badge on the table when working behind a desk: P7: *"I think a combination hand and belt. Mostly I would be in the office and I would just leave it on the desk and if I want to take it with me, I would place it on my belt."*, P6: "*The best reference will be when it is on my desk in front of where I am usually working. I would however be challenging when walking around because I don't want to have it in my hand. The best thing would be if it then would be some kind of watch or a strap."* and P1: *"So, Basically I think the ideal would be a hybrid option [hand and wearable] but then the belt clip option."*

These hybrid options should however still fit the daily wardrobe of individuals, where individuals have the option to wear the badge on them: P5: *"You cannot use the belt clip with a dress. Then you could use a strap to tie him to something .... Of course, it also depends on your dress, but you couldn't hang it like that or you have to have something of a loop, but it's trickier than with pants."*

5.1.3 Form and Social Visibility. The form of SensorBadge was discussed with the participants. Overall, the form was appreciated by the participants, expressing that it fits with a normal badge holder. Some participants (N = 5) indicated that, when possible, it would be *P1, P3-6: "the smaller the more desirable",* but it was not a must to use the design. The weight of the badge was however indicated as an issue by some of the participants for the key cord and belt clip position: P3: *"In the beginning when I had it hanging on the keycord, I thought it was heavy. Not super heavy but you can feel it hanging"*, P4: *"Hanging on your pants works of course, but it is a bit heavy now."*, P4: *"At that time I mainly sat so it is not so bad and then it is not heavy or large, but if you walk with it, it is a bit."* and P6: *"I think the badge is just a bit too heavy but that's understandable because there is a lot in it."*

SensorBadge was worn on the clothing of individuals, making the badge visible for others to see and comment on. This was seen with all positions, most commonly with the belt clip (N = 3) and in lesser extend with the key cord (N = 2) and hand held (N = 1): P1: *"It was noticed by one of my colleagues who asked about it and why I was wearing it."*, P5: *"Someone was wondering what I was wearing (not a colleague), she thought it was a funny looking box"*, P3: *"Yes, they were asked about what it was and why I was carrying it."* and P6: *"Yes, one of my colleagues walked past my desk and noticed the SensorBadge"*

5.1.4 Data Sources and Additional data. SensorBadge collects 5 types of data: temperature, humidity, sound, light and steps. All 5 types of data were indicated as relevant for a healthy office environment by the participants. The badge collects data about the office environment and the physical activity level of individuals. Participants (N = 4) indicated that additional to SensorBadge, personal, data would be relevant for a healthy office environment. This additional personal data would be used to learn how environmental data relates to their circumstances relating to their stress level and productivity: P1: *"I would find it interesting to see if certain factors influence have on my stress level... But then it is important to know if I can do something about these factors. For example, if my stress gets higher when the temperature gets higher then I can do something about it."*, P2: *"Perhaps stress, because that question does appear in the survey. Heart rate possibly. To check for me which situations are more stressful and how I could reduce this."*, P3: *"I think the stress factor is also important to me, perhaps the most important. Because with me it goes up and down with stress and then it's important to know how I can regulate this. For example, how stress relates to other factors such as the sound."*, P2: *"For example, if a lot of light for me lowers my productivity, then it would be interesting to know and then, for example, I would be able to sit in a slightly darker place"* and P3: *"Yes in itself it is the right data, but it is also important to me that I know more about the work situation and myself. So, as said before, productivity, but also whether I am stressed or not."*

5.1.5 Data Quality and Accuracy. As part of the research, the influence of the position of the badge on the data quality was studied. Participants (N = 5) indicated that some of the collected data might not correspond with their experience of the data. An example of this was when the light was measured. When wearing the SensorBadge in the belt clip or key cord position, the light level is measured underneath the table. The light data therefore might not correspond with the experience of the user: P1: *"How you can measure the light level there [belt clip] ..... Because if the badge is under your desk, you are not measuring the light that comes from above"*, P4: "*Because with both the key cord and belt clip it can hang somewhere underneath so that it measures less light."*, P6: *"If I have it either on the belt or the key cord, it's generally below the desk so I cannot get enough readings."* and P7: *"I think it is because of the position. At some point, I realized that I had the sensor upside down and I remembered to switch the sides. So, I could get the reading for the light. And of course, if I have it either on the belt or the key cord, it's generally below the desk so I cannot get enough readings."* This was also seen from the sensor readings. The data shows a difference in light level depending on the position of the badge (Figure 5). Overall, lower values are seen in terms of light data when using the key cord and belt clip positions.

An issue was also seen in the collection of sound data. The measured sound level of the SensorBadge was not necessarily similar to the experienced sound level of the participants. Participants used headphones while working and therefore did not experience any "noise", P1: *"When I sit down while working, then I always use headphones and that this has active noise control and actually then I don't hear anything about the situation around me"* and P6: *"I usually use headphones, so I don't really hear what is happening around me. So, in that way the sound that is measured is not the same as the sound that I experience."*. A similar issue, relating to the the quality

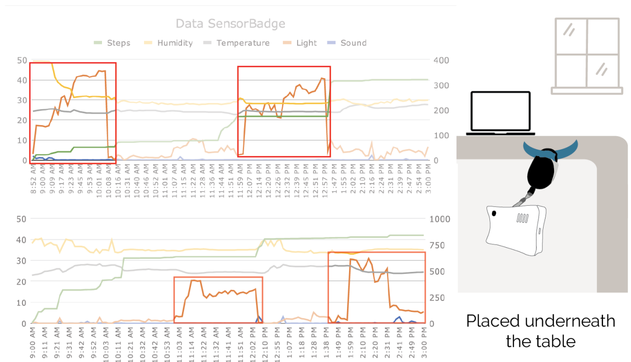

Figure 5: Effect of the position on the SensorBadge on the data, with the light data being influenced due to the key cord and belt clip position. The graph (orange areas) show only high values when the badge in the in hand held position

of the data, was seen in the sensor readings. Participants indicated that the SensorBadge was hitting the table in the key cord position. During the key cord period, several spikes in the sound data are seen (Figure 6). Participants related these spikes in the data to moments when the badge hit the table. P4: *"Yes, the sound there may have different peaks because it was hitting against the table."* and P5: *"And those peaks in the sound are just when I wore the key cord so it was probably when it hit against the table."*

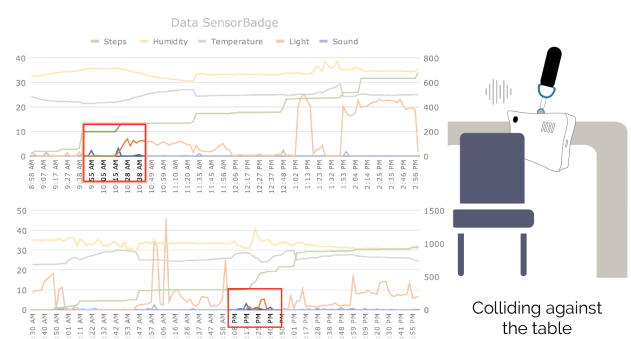

Figure 6: Effect of the key cord colliding with the table on the sound data. The graph (orange areas) show spikes in the sound data when the SensorBadge collides with the table

When discussing the data dashboards, participants saw a pattern between the data and the sensor readings. A pattern was seen when participants change to a different office environment. When participants walked to different environments (multiple steps to a different environment, not changing position in the same location), results in a change in data in steps, temperature and humidity data (Figure 7). This was confirmed by the experience of the participants: P5: *"Every time I walk, I see a "change in data" because every time I walk the temperature goes down, the humidity goes up. We often have the window opened and changed the heating as it was so hot, but it constantly measures that I switch rooms."*. A similar was seen when participants were asked about a similar change in light, steps, temperature and humidity data at a certain moment: P3: *"That's when I went for coffee and for a walk"* and P1: *"Well as said during lunch I have a walk around the couch and have a drink get up and go to the bathroom."*

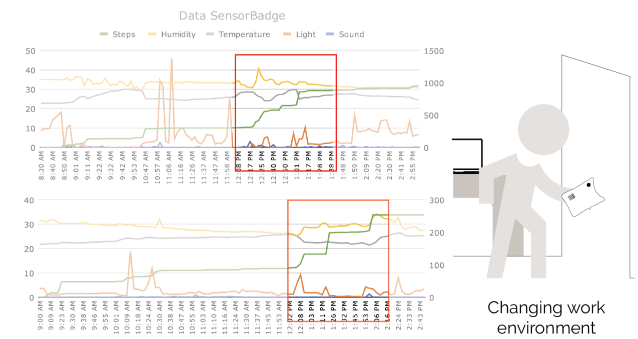

Figure 7: Data pattern when changing office environment. The graphs (orange areas) show a similar combination in changes of data (rise of steps and humidity and decrease in temperature) when individuals change environment

5.1.6 Data Output and Meaning. Data from the SensorBadge was presented to the participants via the data dashboard, which is commonly used by data related services to visualise the data (E.g. Fitbit). The data dashboard presents the data via a graph with the units of the sensors being steps (physical activity), lux (light), degrees Celsius (temperature), percentage (humidity) and volts (sound). Those units, combined in a graph, are however hard to understand for individuals. Participants (N = 6) have a general understanding of the temperature and steps, but are not familiar with the presentation and interpretation of the other units: P1: *"For example light [the data in the graph] or something, doesn't tell me anything at all, whether this is high or low and whether this is good or not"*, P2: *"Well, at first the units of the data mean nothing to me. Because I am never really concerned with that. I am, for example, never concerned with how much light I see in a day."*, P4: *"The only thing I could imagine is the number of steps and the temperature. But humidity, light and sound I have no idea how this is expressed and what this could mean."*, P5: *"I have to take a good look at it [the graph]. If I look at it quickly, I can't get a lot of information from it, but it's not a tricky graph."* and P6: *"I work with data a lot. But I assume some who are not that familiar with data, will be different. For example, with light, I think the unit will be in lumen or lux and not everyone will know that."*

Participants (N = 5), therefore, opted for other options to present the data, in the form of classifications or via pop us and applications: P2: *"What would be useful for me is a clearer output, for example, the classifications of light."*, P3: *"For me, it's better if it's not in a graph, but for example what you see on your laptop like a popup. Like getting a message: It's getting too hot now."*, P5: *"I think it would be better if you could do that via an app or on your computer, for example showing when the temperature changes a lot within a certain time."*, P6: *"So, it will be important that you give them a "high" or "low" type of categorical classification. That would be nice if you want to* *generalize the product."* and P7: *"for example, with a VOC sensor, that the user will get some kind of warning instead of actual data. And this information [actual data and graphs] could still be interesting to provide to users that might be interested in raw data. But I think that a type of warming system would be the right step."*

5.1.7 Putting feedback into Action. SensorBadge aims to provide users with insights into their office environment. These insights could give an individual the chance to change their environment to a healthier setting. The feedback of the badge should however be put into action. Office environments should provide users with the option to change their environment by, for example, being able to open windows, sit in quiet spaces or change the light: P1: *"I think this data is interesting for me if I can also change something about my workplace. For example, if there are also others in a meeting and this can also be more difficult."*, P2: *"When I see that I am ineffective when there is a lot of noise and I can't do anything about the noise then I have something like "don't show it" and then I'm just not aware that I'm doing something and be less productive"*, P3: *"That you adapt the workplaces to it [based on the data] or sit on the other side of the building so that I am more functional. But then it must be an option because it is now not. So, you have to be able to convert the data into actions."*, P4: *"If there really are no opportunities to change the environment, then it doesn't matter what feedback the device gives."*, P5: *"I would listen less well to a system if I can't change my environment."* and P7: *"if SensorBadge somehow knows that I work in a room that has no ventilation or no option to turn up or lower the heat then I guess the system can give me different suggestions, like to out of the room for a couple of seconds or minutes"*

An additional aspect that was pointed out, addressed the social aspect of the data insights provided by SensorBadge. If several people have insights about their office environment and want to adapt their environment based on the feedback, then conflicts could arise: P5: *"Because if everyone has insights into their own data, everyone will adjust their own working environment. So, we have to be able to adjust this [the environment] otherwise the data is useless. So, there must also be a good balance between what different people want."*

5.1.8 Ego-centric vs Place-centric. SensorBadge is a personal hybrid sensor system that collects information about the work environment of individuals, accessible and relevant for the users. The current sensor system hides this information away in an office building with no access to the data for the users: P3: *"I like that the information is now available, which is normally hidden. In [the building the participant is working] the blinders sometimes go automatically down, and for some, this is nice and pleasant, but for others, it is not necessary. So, on this in this way, the personal and personalized information is certainly of added value."*, P5: *"I certainly think if you move a lot, it is more useful to know that [data about your environment], than when you sit in a single room, or when you go through different rooms and buildings move around."* and P5: *"Especially if you move a lot and if you work in different locations and also when you work at the office, at home and in locations further away with colleagues, that you just know what your environment is like and the fact that you anticipate based on this."*

SensorBadge is developed as a system that not only provides users with the option to measure their office environment but also their home-office environment. Participants (N = 5) also reflected on the role of the SensorBadge within the home setting: P3: *"I think I would find it even better for home use. Because I trust this building reasonably. But at home, I have no idea how the quality of my home-work environment is."*, P4: *"I think that at home, you have an influence on everything that happens, but then it is relatively easier to avoid the circumstances and then you don't really need such a device."* and P6: *"I would be nice to use it at home, but I doubt I do it. . . .I also do other activities like cooking, so it would be evident that my environment is not in the right conditions. But it would be nice for me to know if a certain condition is not good, like the temperature or the light then it would be nice to know"*

5.1.9 Potential Long-term Role of SensorBadge. SensorBadge was experienced by the participants for 12 hours. Participants (N = 3) did however have the opportunity to reflect on the role of SensorBadge over a longer period. This includes the use of guidelines and patterns to learn which setting helps to create a productive and healthy office environment: P3: *"I also think the Badge is interesting to get some sort of guideline. That you kind of know, I perform the best with so little stress, this heat, this light, but also that you adapt the workplaces to it or sit on the other side of the building."*, P4: *"If you get information over a longer period, then I think that at some point you will recognize it as "o yesterday it was 40 and now 30" and then you can do it compare and then also understand more what that data means"* and P5: *"It could also work over a longer period. Then you have to keep track of which settings and values work for you. And maybe other factors to take with you that also influence, or where you sit."*

5.2 Experience Sampling

The 3 positions of the SensorBadge (belt clip, hand held and key cord) were experienced by the participants for 2 days. After each hour, the participants were asked to reflect on the wearability, appropriateness, on-body location and collected data.

5.2.1 Belt clip. The belt clip position for the SensorBadge was overall experienced positively by the participants (Figure 8). This was seen in the on-body location, wearability and appropriateness for the current work activity. Overall, for all four statements on the belt clip position, participants agreed with the statements: data collection (Agree: f = 16/28, 57,1%, Strongly Agree f = 1/28, 3,6%), on-body location (Agree: f = 13/28, 46,3%, Strongly Agree f = 11/28, 39,3%), appropriateness (Agree: f = 15/28, 53,6%, Strongly Agree f = 7/28, 25%) and wearability (Agree: f = 19/28, 67,9%, Strongly Agree f = 7/28, 25%).

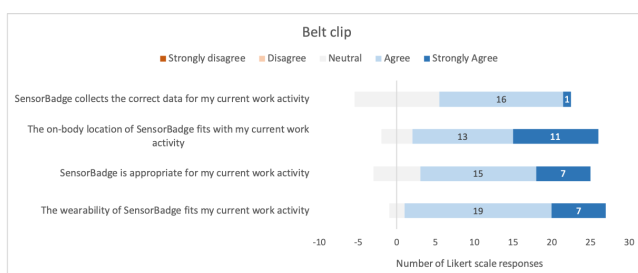

Figure 8: Divergent bar chart of the Likert scale questions of the Belt Clip position

5.2.2 *Hand held.*

The hand held position was experienced less positively compared with the belt clip position (Figure 9). This was seen in all four of the categories, mostly in the on-body location. Overall, the hand held position was evaluated positively with: data collection (Agree: f = 19/28, 67,9%), on-body location (Agree: f = 16/28, 57,1%, Strongly Agree f = 3/28, 10,7%), appropriateness (Agree: f = 16/28, 57,1%, Strongly Agree f = 5/28, 17,9%) and wearability (Agree: f = 18/28, 64,3%, Strongly Agree f = 5/28, 17,9%). However, participants also experienced the hand held position negatively: data collection (Disagree: f = 1/28, 3,6%), on-body location (Disagree: f = 3/28, 10,7%), appropriateness (Disagree: f = 2/28, 7,1%), and wearability (Disagree: f = 4/28, 14,3%).

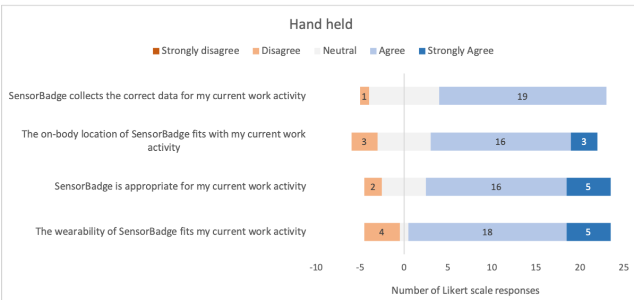

Figure 9: Divergent bar chart of the Likert scale questions of the Hand held position

5.2.3 *Key cord.*

The key cord position was, compared to the other 3 positions, as the least favorite position (Figure 10). This was mostly seen in the on-body location and wearability of this position. A mixed response was seen being both positive: data collection (Agree: f = 15/28, 53,6%, Strongly Agree f = 1/28, 3,6%), on-body location (Agree: f = 11/28, 39,3%, Strongly Agree f = 2/28, 7,1%), appropriateness (Agree: f = 22/28, 78,6%, Strongly Agree f = 1/28, 3,6%) and wearability (Agree: f = 14/28, 50%, Strongly Agree f = 2/28, 7,1%) and negative: data collection (Disagree: f = 1/28, 3,6%), on-body location (Disagree: f = 9/28, 32,1%, Strongly Disagree f = 2/28, 7,1%), appropriateness (Disagree: f = 1/28, 3,6%), and wearability (Disagree: f = 11/28, 39,3%).

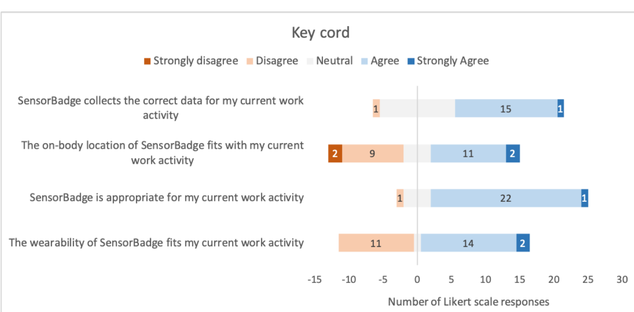

Figure 10: Divergent bar chart of the Likert scale questions of the Key cord position

6 DISCUSSION

This study focused on the wearability, on-body location and data collection of hybrid, wearable sensor systems. SensorBadge presents users with an ego-centric, human-data approach in its data collection. The artifact provides users with insights about their office to create healthier work styles and environments. In this discussion, we reflect on the form factor, data output, putting the data into action, ego-centric approach, sources and accuracy of such systems.

6.1 Form factor: Wearable Design Options

SensorBadge was experienced in 3 positions: hand held, key cord and belt clip. Overall, the belt clip position was identified as the preferred position by the participants. This position costs the least effort and fitted seamlessly within their workday due to individuals not having to think about the artifact and the artifact not interfering with their work style and pattern. However, this position effected the data collection when collecting data about the light level (badge placed underneath the table). The option of a hybrid wearable placed on the body via a belt clip and hand held was therefore opted as the ideal situation where individuals can change position based on their preference, clothing, work requirements and workstyle [24, 57, 60]. This shows the overall importance of the form factor of wearable office vitality interventions in the overall everyday office setting within the artifact [57]. An important challenge here is the transition from one position to the other. The positions should strengthen each other (e.g. collection the data accurate on a desk, while wearing it on your body with a belt clip when moving location) instead of weakening each other (e.g. forgetting the SensorBadge when using hand held, while moving location or placing the SensorBadge underneath the table while working). The artifact should therefore facilitate the transition from a position, to provide users with the best on-body location and accurate data [53].

The weight of the badge was indicated as the most common issue of the SensorBadge. A large part of the weight of the badge consisted of the battery (battery weight 40 grams which is 42% of the total weight). The weight can therefore be easily lowered by using a smaller, less heavy battery. However, lowering the battery will decrease the battery life of the artifact, potentially leading to a data loss, when forgetting to charge, and a higher effort from users [67]. A challenge is set here to find a balance between usability and wearability where users can use seamlessly use the SensorBadge without creating additional efforts [24].

6.2 Data output: Understanding the Data

The data from the SensorBadge was presented in the data dashboard via a graph while also showing the units for the sensors (number of steps, humidity percentage, degrees Celsius, lux and volt). Novice users have problems reading off these values and making sense of the data [16, 53, 61]. To make sense of the data, experts need to analyze the data for users to interpret it [16, 61]. When not including an expert, individuals learn from the data when relating the data pattern towards their routines or discussing it collectively. However, this approach leads to assumption-based interpretations leading to speculations on the situatedness of the data [31]. Data, therefore, needs to be classified and presented in a way that is understandable for novice users. However, there are interpersonal differences in terms of perceived comfort within these classifications. Users can be asked how, for example, how hot, cold or comfortable they feel in a certain setting and incorporate this in the evaluation. The incorporating of user feedback into the data collection is one of the challenges for the future development of wearable sensor systems [73].

Fields such as digital visualisation and data physicalisation can offer solutions in the presentation of data. These fields offer the opportunity to present data, including the classification of data, in an understandable way. The digital visualisations could however have less impact due to the lack of social visibility [7] or display blindness [42]. Data physicalization can offer a solution in presentation of the data in a non-digital way. Data physicalization can be compared to the presentation of data in the form of a (digital) graph, bringing digital data to a human-readable representation [26]. Data physicalization supports data analyses through the visualization and support of human-computing interaction through physical objects. The translation from digital data to a physical object can help novice users to create an understanding of the variety of data that is measured in their environment [26].

6.3 Putting Data into Action

SensorBadge provides individuals with an overview of the environmental characteristics of their work environment. Feedback should not only give insights but create possibilities for individuals to take action. These actions should however be possible. A scenario that was mentioned by several participants was that they are not always able to take action due to the restrictions of the building (e.g. not having a window to open, when the temperature is too high). Employee control plays a major role here where individuals have control over their physical work environment and change it to improve their health and well-being [54]. Personal control over the work environment has been proven to decrease the negative effects of distractions and inappropriate working condition and reduce stress [36]. However, there is still a challenge for individuals to control their work environment. This has increased with the open-office plan [54]. The office environment should therefore provide individuals with the control (e.g. light, ventilation, office setting) over their work environment to improve the overall well-being of office workers [5, 54]. The level of control is however a challenge for future research. If everyone has control of their own office environment conflicts could arise if individuals have competing interests. A balance should therefore be found between the interpersonal differences and preferences to create a level of control which can increase the overall office well-being.

6.4 Ego Centric vs Place Centric Design

SensorBadge provides an individual with information about their office environment which is usually hidden within the building as a place-centric stationary systems [72]. The ego-centric approach in SensorBadge provides users with the possibility to bring a personal, hybrid sensor system that moves with the user throughout the day, taking a Human-Data approach [41]. The hybrid artifacts also give users the option to use it in different work settings, including home office settings [44, 68]. With the development of new, ego-centric, wearable artifacts comes user acceptance, ergonomic design principles and user-friendly solutions of wearable technology which are key aspects that are highlighted for environmental monitoring within wearable artifacts [53]. This new, ego-centric approach in Office Vitality and office sensor systems shows a promising area for future research and design artifact development.

6.5 Data Sources and Accuracy

The SensorBadge collects both environmental data (temperature, humidity, sound and light) and personal data (steps). Additional data sources such as productivity and stress were opted as personal data sources which should improve the overall well-being of office workers. These data sources should provide an overview of if and how the work environment could potentially influence these factors. The combination of environmental and biometric/physiological data combined with subjective feedback is an aspect that could be explored further in the future, taking a human-centric approach [47, 53]. Data sources like stress and productivity will be hard to measure with a wearable, environmental sensor system like SensorBadge. Products and programs such as RescueTime (productivity) and activity trackers (heartrate and stress) could provide a solution when combined with the SensorBadge data to measure and learn how the office environment influences factors such as stress and productivity. These combined sources can then also be used in future scenarios where machine learning is used to, based in a larger database, recommend healthier and personalized work settings, depending on tasks, work demands or preferences [48].

A challenge that was identified was that collected data from the SensorBadge was not always similar to the experienced data. This was mostly due to the position of the badge (e.g. placed underneath the table or colliding with the table). Another aspect concerning that was indicated was the difference of experience data vs measured data (e.g. working with headphones, while the sound was measured). These findings show a disadvantage that mobile sensor systems can have due to their non-stationary position. Mobile sensors systems are in general, less accurate than stationary sensor systems [24, 53]. Hybrid systems (combination of mobile and stationary systems) are opted as solutions to overcome this in-accuracy of mobile systems [24]. This combination of sensor systems does increase the overall costs of the sensor system [24]. An interesting step for future work is to learn how these systems can strengthen each other to improve the overall well-being of office workers.

6.6 Limitations and Future Directions

Participants were asked to wear SensorBadge in 3 fixed positions. There are however other positions (and combinations of positions) in terms of how the SensorBadge can be worn [60]. Other positions could have different effects on the overall experience, data quality and wearability of SensorBadge. SensorBadge was also mostly used in an office setting. Only two participants used SensorBadge in the home, office setting and therefore could reflect on the potential role of SensorBadge as a hybrid sensor system. SensorBadge could have a different effect in the home, office environment. Individuals might be less likely to wear a sensor badge at home and adjusting the temperature within you own home might be easier than at work. Future research should indicate how the position of SensorBadge can be used and changed towards different work tasks and environments as well as more indepth knowledge on role of SensorBadge in hybrid working settings.

The overall form and sensor placement of SensorBadge were evaluated during the research. The findings of the study show a wrong placement of the light sensor on the badge. The light sensor was on the bottom part of the badge. This placement resulted in some inaccurate reading in the data. To improve the overall accuracy and quality of the data readings, all sensors which measure the environment (e.g. light, sound, temperature) should be placed in a similar position within the artifact. The equal placement of sensors will provide a more accurate view of the environment of individuals to learn how their environment changes or if they change the environment themselves.

SensorBadge was experienced for 2 days by the participants, to create an understanding of the initial experience of SensorBadge. The goal of the research was to evaluate the on-body location, wearability and data accuracy of the artifact. These questions need to be answered and implemented in a future improved design before a longer study can be conducted to gain an understanding of influencing the long-term office well-being of individuals. The next step in this process will be to develop an improved artifact that collects several environmental and personal (from both internal and external sources) data. This artifact should be evaluated in a longer, more extensive research to gain an understanding of influencing the long-term effects of SensorBadge on the well-being of office workers.

7 CONCLUSION

The current office environment sees a place-centric approach in both office vitality interventions and monitoring the office environment. With SensorBadge we take a new, ego-centric approach where we place the user in the center of the data collection. From a broader perspective, our study shows that, when designing these forms of wearable sensor systems, the artifact should fit seamlessly in the office routine of individuals, not requiring extra effort or creating conflicts with the work pattern of individuals. Data should be classified and presented to individuals in an understandable way, moving away from graphs and numbers. Individuals should however be able to put the data into action, providing users with a personal control of their office environment.

With our research, we contribute to the field of Human-Computer Interaction (HCI) by creating an understanding on use and development of wearable sensor systems in the office environment taking an ego-centric, human-data interaction approach. The produced knowledge is relevant for both the development of design interventions and research setups on the timely topic of wearable sensor systems in the office environment.

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