Alleviating Struggles at the Office: Leveraging Mobile Sensing to Understand and Counteract Issues

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ABSTRACT

Mobile sensor technology, such as wearables, has been growing and evolving in recent years. Despite this, HCI designers and companies, particularly in the fashion industry, have yet to improve on explicitly designing portable solutions; optimally so that they effectively support users in reflecting and raising awareness on issues, a challenge also relevant when designing sensor solutions for offices. As of now, HCI designs were found to focus on precision, accuracy of monitoring, and effectiveness of classification model training rather than on wearability, aesthetics and, comfort. A shift in design thinking is thus necessary to reach mass adoption: designing mobile sensor solutions so they can be integrated into conventional items, especially fashion products. By evaluating practical mobile solutions on their supportiveness of reflection and signal processing in the context of the office, this paper puts forward guidelines to help HCI designers conceptualize mobile solutions, specifically for the office environment.

CCS CONCEPTS

• **Human-centered computing → Mobile devices**.

KEYWORDS

wearable sensors, reflective HCI, office technology, design education

1 INTRODUCTION

Office work increasingly gets more common, a trend with no end in sight. According to a study published by the German *Interior Business Association*, 71% of the German labor force (ca. 32M people) have worked jobs that at least partially take place in an office in 2019; a number that amounted to just 52% four years prior.[14] Through the spatial restriction of offices, movement is limited, immediately suggesting health issues that need effective tackling. HCI designers have so far missed out on pursuing this deficit as an opportunity to create supporting mobile reflection solutions for the masses. Reviewing existing conceptions and subsequently deriving their shortcomings and strengths was therefore necessary. Therefore, this paper explores how current technology helps alleviate reflection of health issues and other struggles faced by office workers. The scope of this paper is further limited to *mobile* sensors only. Properties common to such are *portability* and independence of both time and place (colloquially: "always ready to use"), excluding invasive sensors as a result.[8] Mobile sensors also need to be distinguished from *stationary* ones, which are inadequate due to fixation. A practical stationary concept is the slow robots solution for unobtrusive posture correction by Shin et. al (2019) which employs a robotic arm.[12] It has been shown that recent mobile sensor solutions lack in wearability, aesthetics and comfort, requiring a shift in design thinking; a shift this paper tries to leverage by submitting guidelines for the conception of mobile sensor technology.

2 TERM DEFINITIONS AND CONCEPT

2.1 Definitions

Signal. In further use, the term *signal* will refer to any kind of data collected by any type of sensor such as weight measured by a scale.

Reflection. This is a rather complex term defined by less than every second paper. In place of precise formulations, descriptions often serve as definitions; like such that regard reflection as a "conscious, purposeful thought that is directed at a problem to understand it and form integrated conceptual structures,"[1] or as a process “in which people recapture their experience, think about it, mull it over and evaluate it”.[1] In short, designers can support reflection by informing users about their behavior, for instance, by giving them lists of collected personal information to look at or information visualizations to interact with and explore. Furthermore, various authors draw on two definitions by Schön’s "The Reflective Practitioner" (1983): *Reflection-on-action* and *Reflection-in-action*.[2, 11] The first could be summarized as the study of patterns in order to gain knowledge; especially as to improve and find "success". The latter could be seen as an act of comprehending and adjusting “on the go", meaning that it takes place whilst that which would be reflected upon is happening.[11] Both these definitions as well as the commonly attributed trait of being the means to an end (e.g., improving education or understanding illness better) constitute the further use of the term.[1] It is to be noted, however, that the method and purpose of reflection can change with time.[10]

2.2 Wearables and their role in reflection

A popular practical application of mobile sensors are wearables. These are small electronic devices, often enabled for wireless communication and come in both *invasive* (e.g., microchips) and *non-invasive* (i.e. clothes and accessories) variants. In addition to being portable, convenient, and hands-free, they set themselves apart from popular technology like phones through further features such as additional monitoring and scanning capabilities (e.g. biofeedback).[9] Their ultimate value, however, lies in the capability of sensing and analyzing physiological and psychological data (i.e. feelings, sleep, movement) through close use on or around humans.[4]

Types of wearables. Khakurel et al. (2018) define five categories for wearable technology usage: monitoring, tracking, assisting, augmenting and delivering content. Only the first two of these categories will be considered in the following, with *monitoring* referring to the capability of observing collections of quantified self-data, mostly for later classification (i.e. recognizing moods of employees through data on skin conductance) and *tracking* referring to the capability of (non-stop) recording any kind of data. These two categories evidently complement each other as tracking enables monitoring.

Reasons for Wearables in the Office. Before examining concrete issues in the office, it is worth looking at why to use wearables. As they enable humans to quantify their "self", wearables have been found to improve health, safety, and well-being in the workplace, often through interventions. In regards to the meaningfulness of said task, they even outperform interviews or questionnaires. A concrete example is mood prediction through physiological data. Using wristbands and chest sensors to collect this kind of data, employers have been able to make better decisions in terms of relieving employee stress and fatigue.[4]

3 RAISING AWARENESS THROUGH SIGNALS

3.1 Relation of issues and signals

Looking at why (health) issues and signals are related, it quickly becomes apparent that such problems often, though not only, stem from personal characteristics including behavior (diet, physical activity) and genetics. As previously shown, such attributes can be quantified and thus used to quantify humans, establishing a direct relation between (health) issues and (data) signals. In order to derive relevant data signals, it is thus necessary to consider which health issues are common in office workers.

3.2 Reflection and Awareness

With the relation between issues and signals established, what's left is a more concrete definition of awareness in the context of reflection. It is the consideration of data signals that leads to awareness; a process called *reflection*. Li et al. (2011) subdivide this process into two phases: the *maintenance* and the *discovery* phase.[6]

Humans typically enter the Maintenance Phase with predefined *program-level goals* which are small concrete steps that lead to a more abstract goal (e.g. walking 10 000 steps a day in order to get fit). Trying to stay in line with such goals leads to questions on *status* and *discrepancy*. Getting this kind of insight should be understood as *awareness* within the maintenance phase and is commonly achieved by reflecting only on those signals which affect the behavior relevant to set goals. Examples are expenses and time spent productively. In contrast, humans do not know of such program-level goals when in the *Discovery Phase*. The reason for this is a lack of understanding of which factors influence their behavior, often resulting in the collection of all kinds of data in order to make out correlations. Successfully working these out, so as to be able to enter the Maintenance Phase, can be considered *awareness* in the Discovery phase.

Users can thus return to the maintenance phase once more insight appears desirable (i.e. given a lack of knowledge on correlations). Transitioning from any of both phases to the other is therefore always possible. That's why designers should not design sensor-employing solutions to collect data solely for the means of data collection and reflection. Instead, they should seize data collection as a means to solving concrete and well-defined issues.[6]

3.3 Health issues and their signals

Some of the (health) issues common in office workers will now follow in order to better understand the issue-signal-relation. Take, for instance, excessive work demand, psychosocial work stressors, and behavioral responses in computerized work environments. These affect and increase the risk of musculoskeletal disorders such as pain in the shoulder, back, and neck. Signals hence relevant include the time of keyboard usage (causing strain), worker-workstation-alignment (affecting posture) or time spent in one posture.[5]

Considering the office is an indoor environment, environmental factors such as air pollution (i.e. mold and dust) matter as allergy suffers could be amongst workers. For this, logs of both well-being and allergic reactions are imaginable signals.

Realizing the primarily *sedentary* nature of office work is necessary for the last consideration as the limited amount of physical activity causes low physical fitness (leading to increased risk of ischemic heart diseases) and a higher rate of obesity. Derivable signals are thus steps taken or any kind of physical activity (walking, stretching, short workout).[5]

4 SELECTED MOBILE SENSOR SOLUTIONS

With terminology and all conceptions established, considering how and to what extent signals of selected real-world mobile sensor solutions for the office affect awareness can now follow. Before, it is necessary to establish that most *office-centric* solutions are inadequate to this paper. The reason for this is that they primarily employ stationary sensors. Examples are posture-detection solutions such as pressure-sensitive floor mats or camera-based systems as presented by Khakurel et al. (2018).

4.1 Posture correction

Clemens et al. (2007) set out to design a posture movement classifier that would employ mobile sensors. The result is a solution that, being able to distinguish between at least 27 different postures of the torso, is beneficial to office workers, i.e. as a means of recognizing unfavorable back positions when sitting.

Setup, methodology and outcome. The back of a tight-fitting front zipper catsuit was equipped with a miniature thread-shaped strain sensor using silicone film. Additionally, a small data acquisition unit connected to the sensors was placed on the waist of users in order to record data which it would transmit to a PC via Bluetooth. The measured strain data is then saved in a file, serving as a feature set for posture classification. An additional GUI can visualize this data. The three models explored in the paper are the user-specific (97% accuracy), all-user (84%), and new-user (65%) models, the last of which fails to differentiate between standing and sitting.

Signals. Solely the strain sensor readings have been used in order to classify upper body postures, which, coming in different intensities from all the single strain sensors, absolutely suffices. Though the solution has yet to be tested on authoring-outsiders, thus lacking a review of user reflection, the authors could establish three detectable properties for workout sessions: the respective number and frequency of repetitions, as well as the speed and range of movement.[8]

Review. The sensors employed in the solution are mobile as required. Considering one *specific* garment is equipped with these sensors, it is questionable how easy it would be to equip other clothing every new day. Due to its unconventionality, equipped clothing may also cause social stigma. Moreover, despite not having been tested in the office, utilizing the solution as a reminder to occasionally change posture or stretch are nonetheless imaginable applications. Awareness could therefore be raised by *discovering* unhealthy postures, as well as intervals spent in certain postures in order to develop and *maintain* a habit of optimal sitting. Furthermore, reflection could be made easier by designing solutions so they can differentiate sitting and standing, a distinction essential to office workers. Additionally, users should be able to train the user-specific classification models themselves. This could be done via *user feedback* using the visualization application mentioned in the setup. All in all, reflection and awareness have not been a point of interest to the Clemens et al. (2007), but there is, as just shown, an *opportunity* to help with reflection.

4.2 Stress Management

Sanches et al. (2010) present in their work a stress management biofeedback mobile service for everyday use with a focus on high wearability (i.e. comfort and unobtrusiveness). The authors aimed at helping non-expert users *reflect* on two types of behavioral patterns in personal data histories: negative patterns, as in those causing stress, and positive patterns, as in those that help with coping. A test user remarked the system helped them increase their body awareness, as awareness of the severity of their personal stress situation grew.

Setup and Process. Through comparison to existing solutions, the authors found most were designed for sporadic interaction rather than for everyday use. Filtering by this criterion, the selection narrowed down to skin conductance, heart rate, pedometer, and accelerometer sensors. As for designing reflection support, medical research on stress symptoms made them question the "diagnose-and-warn" approach, realizing (1) the subjective character of experiences of bodily conditions, that (2) a diagnosis without non-invasive biosensors is rather difficult, and that (3) the quality and meaningfulness of signal data is highly dependent on the placement of sensors. Nonetheless, they iteratively tested the selected sensors in solutions that have been created and improved along with actual users. Throughout these tests, the suitability for everyday use and the quality of stress signals of the sensors were of particular interest. The recorded data is then transmitted onto a phone via Bluetooth in real-time. Within the testing stage, the authors could establish a few user-relevant *experiential qualities*; with one of them being the *history of prior states*, which found its way into the interactive application as will be considered in the review.

Relevant Signals. The primary signals are heart rate and skin conductance levels, both of which are related to overall stress arousal, thus giving insight into stress responses. Since arousal levels don't suffice to tell if a response trigger was positive or negative, users need to help classify changes in arousal. Accelerometer signals assist the user in recognizing which activity could have triggered the response (e.g., a workout), thus serving as a context reminder.

Reflection and Awareness. For the reflection support design to help users understand and experience *actual* emotions, the authors went out of their way to design an emotion-responsive experience instead of only presenting discrete measurements. The goal was hence to design an interface that would represent measured short-term stress so that users could relate stress level changes to inner experiences for classification. As such, it was necessary to pick a form of presentation that wouldn't suggest that spikes imply more and drops less stress but instead increased activity. Their solution was the use of color, with blue indicating low and red high arousal levels – a common association in the west. They also went on with shape and animation in a similar fashion.[10]

Review. All sensors employed in the solution were mobile and created with design and social stigma in mind. The last aspect is questionable, however, considering a skin conductance sensor-equipped sweatband is rather prominent. An industry solution should take better care of aesthetics, for instance by manufacturing a proper (metal-built) bracelet with sensors on the inside. The authoring team also honorably considered the reflection-awareness relation. Good examples are the mentioned uses of color for trigger sentiment distinction, animations for the communication of liveliness, and the arousal state history for classification context. As for how reflection could be further improved it is first necessary to understand that not all problems can be effectively alleviated through *unobtrusive* solutions, a fact mentioned by the authors. It is also imperative to explicitly test the solution in the office environment with stress being the second most severe work-related health issue in Europe [3]. In any way, helping users discover triggers of negative and positive changes in stress supports the development phase of reflection. Adding additional signals related to the stressors unveiled throughout the development phase could be an opportunity to improve support in the maintenance phase.

5 SUMMARY

5.1 Conflict of Design Ideals

It appears researchers focus on precision, the accuracy of monitoring and effectiveness of training rather than on wearability, aesthetics, and comfort. It is recommended to focus on the latter when explicitly designing for mobile use which the second solution is a good example for as the authors set aesthetics as a core design principle. HCI designers can solve this issue by considering fashion and comfort aspects. An industrial example is the *Jacquard Project*, a collaboration of Google and Levi's. The result is a jacket equipped with a smart fabric with built-in touchscreen-like sensibility. Its sleeve acts as an input interface for everyday smartphone functions.[13] Another industrial example is the *Sony Reon Rocket*, a mobile body cooling device that is fashionable and easy to set up and put on, thus overcoming some of the named issues like a lack of fashionability and focus on mobility.[9]

5.2 Critique on Wearables

Wearables often appear to be viewed in a positive light only. But they are, of course, controversial, as well. One such controversy is the quantified self as humans' responses to signal reflection can strongly vary. Awareness might be higher through reflection but one's well-being could worsen simultaneously.[4] An analogy is regular weighing. Throughout the maintenance phase, the focus could shift from checking the discrepancy to a set goal to keeping an ever-decreasing trend; possibly triggering an eating disorder. Other conflicts are privacy and ethics, especially when data is collected in a mass environment like an office. Ethically speaking, self-tracking could be exploited in the interest of neoliberalism, particularly for ultimate efficiency optimization (Neo-Taylorism). This imposes questions of social justice, such as who really benefits (employee or employer).[4] In terms of privacy, data collection itself is disputable. Considering modern humans use multiple data collection devices at once, they are at constant threat as data from various sources can be accumulated to create one big data profile. Considering which data is necessary and where to best store it is thus essential. Decentralized storing is recommended (e. g., on the user's own devices).

5.3 Guidelines for Designing Mobile Sensor Solutions for the Office

What follows are guidelines to improve the suitability of mobile sensor solutions for everyday use, particularly for applications in the office. HCI designers can use these for orientation.

(1) Designers should understand *who* the solution is made for; starting by clearly defining the end-user through characteristics. Examples are behavior, the initial reflection phase, relevant program-level goals, and available knowledge on these goals in the given reflection phase. A concrete example of this is the stress management solution introduced earlier. The authors wanted to find negative and positive patterns in stress arousal in order to learn about triggers, clearly supporting the development phase. In contrast, the posture correction team completely neglected reflection by focusing on making posture correction *at all* mobile when they should have instead concentrated on *using* mobility to help users effectively.
(2) For all health-related, designers should thoroughly review medical findings on the effectiveness of sensors and the optimal form of supportive diagnosis (i. e., how to support reflection effectively).
(3) Before looking for sensors, designers are advised to define quality requirements such as accuracy, applicability (especially in an environment like the office) and adequacy for everyday usage (unobtrusiveness, fashionability, portability). As Sanches et al. (2010) noted, not all issues are best tackled by *mobile* solutions, especially as unobtrusive sensors have been found not to be as accurate and meaningful as wished for. A device equipped with such sensors that can be recommended for data collection and visualization, however, is the smartphone, as it is portable and mass adopted. Benefits the teams around Wang (2016), Manjarres (2019) and Sanches (2010) made use of by developing supportive phone applications.[7, 10, 15]
(4) Before starting with the conception of a solution, designers should research if others have addressed the problem and whether or not the planned concept would add anything new. Such research is also an opportunity to explore which sensors have previously found use and how well they performed.
(5) Conducting the conception and testing phase in close collaboration with the end-user is advised. Enabling users to calibrate, train and improve models is recommended, too. In the posture correction solution, for instance, user-specific models performed well, the all-user model, in comparison, has not. The authors could have improved the results of the all-user model by allowing users to execute training themselves.
(6) In order to effectively support reflection, designers should mind how data is presented. This can be done by determining which reflection phase to support, which signals are then necessary, if additional information is needed (as seen with accelerator data in the second example) and how to effectively make use of data visualization (e.g., through animations). Wang et al. (2016), for example, used notifications and vibrations on a phone in their posture correction solution to alert users about a bad posture.[15] Considering the transitions between the reflection phases are fluid, it is advised to support both. (7) Designers should also keep in mind that interpretation of data representations and visualizations can often deviate from the intended understanding. It is thus advisable to observe how users actually utilize the solution, as harmful misuses are possible.
(8) Last but not least, executing data minimalism and carefully dealing with privacy is imperative. Solutions should thus collect only the most necessary data and inform users on which data it collects, what it uses it for, where it stores this data, and how users can request its deletion.

As established throughout the reviews on the two practical examples, only the the stress management team cared for elements of these guidelines. The result is a product suited better for daily use when compared to the posture correction solution which rather focused on having mobile sensors employed than explicitly serve mobility.

5.4 Outlook

As for wearables, significantly improving battery life and battery changing is vital. *Energy harvesting* could help in this regard but is still far from being mass adopted. For wearable technology to find wider use, it would require integration into conventional items, particularly fashion products. Examples are the mentioned products by Sony and Google/Levi's.[9] Fashion brands, however, haven't been investing much in related research despite having the means to do so. Exploring other product categories like textile-based clothing in order to find a balance between fashion and functionality thus remains necessary.[13] It is worth noting, though, that recently performance-based textiles have been selling better than purely aesthetic textile and that health or fitness serving accessories have technologically advanced most. As for science, further studies are needed on how wearable technology could reduce challenges such as privacy, information ecology, but also on how to improve satisfaction and engagement.[4] Further, more precise research and testing for the use of mobile sensors in restricted environments would be beneficial. Beneficiaries would be wearable manufacturers and potential buyers. Reasons are the growing wearable market (by annually 20%, reaching ca. 150B EUR by 2028) and the expectation of steadily increasing wearable adoption, particularly in the business sector (11.8% annual growth rate in the global enterprise market from 2019–2026).[9]

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