Ambient Information Design for a Work Environment

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Abstract. To empirically investigate the impact of ambient information systems in a work environment, we developed a sensor-actuator system, designed a data mapping choreography, and set up a responsive office to be evaluated by experimental participants. 22 subjects were asked to work in the setting for 90 minutes and to give feedback by means of an online questionnaire and a follow-up interview. Their behavioral and arousal signals were measured and recorded as well as transmitted in real time to office equipment such as lamps, speakers, and a fan to control parameters such as brightness, hue, saturation, volume, speed, etc. to convey ambient information. The focus was on user experience, appropriation processes, well-being, productivity, and design principles for embedded ambient interfaces. The acquired sensor data was used to validate the data collected through the online questionnaire and the qualitatively analyzed interview. The study provides insights into the implications and benefits of embedded environmental information and data mapping design strategies. The paper concludes with experimental design considerations and an outlook on further research approaches.

Keywords: design research, work psychology, sensor actuator system, ambient information system, responsive environment, internet of things.

1 Introduction

This article is based on the experiment *Periphery* of the running research project *Paradigms of Ubiquitous Computing* funded by the *Swiss National Science Foundation* (2019-2023). The project investigates user experience in technologically enhanced responsive environments, and the *Periphery* experiment focuses on their applicability in work situations. We studied responses of the participants of the experiment in an interactive work environment that reflects personal behavior and arousal in real time. We wanted to find out how the ambient display of personal data is perceived and processed, how it influences the work process, and when it is considered to be disruptive or helpful. We examined how participants interacted, adjusted their behavior, and which design approaches and conditions were rated most promising for improving well-being and productivity.

The appearance of the physical environment was restrained and consisted of an arrangement of classic office furniture that offered different work modes. The focus of the design was more on the Ambient Information System (AIS), the mapping design, on how the measured data is translated into spatially integrated physical representations. We developed a Sensor-Actuator System to measure participant behavior and arousal signals and transmit the data to technical devices integrated into the office space. The signals were recorded through positional tracking, detection of head and wrist movement, and heart rate. The data were collected, processed, and assigned in real time to various physical parameters of devices such as lamps (brightness, color, saturation, frequency), loudspeakers (type of sound, volume, audio effects), contact speakers (vibration intensity, interval) and a fan (strength, interval of airflow).

The immersive research facility was evaluated with 22 participants taking into account diversity of age and gender. They were introduced and calibrated following a standard protocol, asked to put on a sensoric wristband and cap for data collection, and to consent to the use of anonymized data collection. Thereafter, we asked them to enter the research facility and to follow their daily business on their personal laptop computers for one and a half hours. In addition to quantitative sensor data, we also collected qualitative data by asking participants to keep an online diary during the experiment and to complete a short interview afterwards. We heuristically analyzed the collected sensor data sets by contextualizing the data curves with the video tracking camera recordings. The interviews were analyzed using Qualitative Data Analysis (MaxQDA) and the patterns found were verified with the results of the online diary and the quantitative datasets.

The study presents findings on user experiences, appropriation processes, well-being, productivity, and data mapping strategies in a work environment with an integrated ambient information system. The paper concludes with experimental design considerations and an outlook on further research approaches.

2 Related Work and Theoretical Background

In this section, we introduce relevant theories and studies in the field of tension between **Science & Technology Studies** (Ubiquitous Computing, HCI), **Design Research** (User Experience, Ambient Information Systems), and **psychology** (Sense-Making, Work Psychology). Throughout this paper, we refer to these terms, concepts, and research approaches.

UbiComp calls for new interaction paradigms that structure the experiences with technologically augmented environments much “more like the way humans interact with the physical world” [1]. For this purpose, it is necessary for computing processes to become “invisible,” which means that they successively merge with the environment. “Invisibility of computing, from the human perspective, can start when we are able to determine an individual’s identity, location, affect, or activity through her mere presence and natural interactions within an environment” [1]. For our experiment, we made the necessary technology as invisible as possible by building it into normal office furniture and turning it into data displays in the appropriate situations.

Ambient Information Systems (AIS) are described as physical, tangible representations of information in the environment [19] and Ambient Displays as architectural spaces turned into interfaces between people and digital information [26]. An inspiration for our experiment was Wisneski et al. [26] presentation of the ambientROOM, a personal interface environment designed to provide information through room interfaces. In addition to those ambient media, such rooms use graspable objects, which pass on information to the users via technical systems such as sound [17], light, or via messages on the phone [11]. Many experiments are already further in the past. Today's technology makes it possible to include reliable measuring devices and systems for experiments at low cost. Some of these ambient media displays are attributable by natural forces such as wind, sunlight, or the sounds of a rainforest.

In 1995, Natalie Jeremijenko [9] developed “The Dangling String” at Xerox PARC, a physical plastic rope that represented tracked network traffic through whirling motion, which is considered to be the first ambient representation of a data flow. Information mediated in this way, is not asking for full user control but occasionally shifts from the periphery to attention [19, 24]. Furthermore, there are already research approaches that examine the individual environment, so-called **Ambient Assisted Living systems**. Such systems are mainly used and researched in the medical environment for the care of elderly people to increase autonomy and support activities of daily living with the help of smart products. [6]. Jara et. al. [6] evaluated NFC communication to perform continuous monitoring of electrocardiogram (ECG). However, it is not only in the context of people in need of support that such devices can be applied.

eHealth devices, wearables and health-apps on the phone can provide personalized biodata in real time and are already on the market and scientifically studied [18]. Such devices have been a big fitness trend in recent years [23] and have been widely used in all age groups [22, 23]. It is no wonder that scientists and professionals are very interested in the potential to provide users with wearable devices to promote physical activity [9, 13]. Rapid advances in technology have led to the automation of real-time activity tracking based on individual goals and public health recommendations, allowing users to self-monitor their activity over time [10, 20]. Further studies confirm that such information can be used for personal interventions to change behavior, increase well-being [8] and, with the right signal, also enhance productivity during work.

In comparison to these mobile devices, that are based on graphic data visualizations and ask for conscient information retrieval, we propose to weave the information into the environment with design qualities. The study provides insights into the users' assessment and allows the derivation of some design principles.

Sense-making refers to a social interpretative process that structures human experience. It is closely connected to the narrative structure of social understanding: past experiences become the basis on which new information, gathered in the present, is categorized and used for the anticipation of the future. According to McCarthy & Wright [14], the cyclical sense-making process consists of six individual phases, namely *anticipating, connecting, interpreting, reflecting, appropriating,* and *recounting*. In our study, the sense-making approach comes into play when we analyze participants' learning, habituation, and judgment processes.

Over the last 20 years, several **HCI** studies have investigated user behavior in artistic interactive installations [5, 16] and UbiComp research settings [3, 21]. Linda Candy and Sam Ferguson [2] give an overview of methods for evaluating interactive art experiences and propose frameworks to identify the corresponding contextual situations, that were useful for our mixed methods evaluation approach.

3 Research Interests

To investigate **user experience** and **cognitive interpretation** processes of test subjects in a work environment with an embedded AIS, we developed a responsive office space. One focus of the study was on the impact on everyday work, a second on the design approaches of data mapping.

We were interested in finding out to what extent the technologically enhanced environment had an influence on the participants' state of mind, whether they perceived it as pleasant or disturbing or even **attributed characteristics** to it. The ninety-minute experiment also allowed us to examine **learning processes** to determine what ambient information the participants recognized without introduction and whether they became accustomed to it.

In terms of work psychology, we wanted to gain insights into the **usability** or possible **implications**, the potential for improved **well-being** or increased **productivity** in everyday work. Because the experiment was conducted in a semi-public space, we were also able to investigate whether participants were uncomfortable that others in the room might perceive their personal state of mind as indicated by the AIS (**data privacy**).

To draw conclusions about the **design of embedded interfaces**, we examined how the different forms of data representation were perceived, comprehended and accepted. Since the responsive office space was staged according to a **data mapping** choreography with different design means, such as light, sound, vibration, and ventilation, we were able to compare concrete design approaches. We asked the participants how they interpreted the different situations, which causal connections they could recognize between their behavior and the space, what forms of interaction and types of media they preferred, and whether they also perceived temporal changes.

4 Research Setting

To study the impact of the AIS on the work environment, we set up a Responsive Work Environment (4.1), developed a Sensor-Actuator System (4.2) and designed an Ambient Information System (4.3).

4.1 Responsive Work Environment

In the *Critical Media Lab* of the *Academy of Art and Design FHNW*, we set up a research facility for the *Periphery* experiment. The name periphery comes from Marc Weiser's concept of **Calm Technologies** [24] which remain in the periphery of attention and come to the fore only when needed in the right context. The staged office space was designed low-key and composed of classic office furniture and some plants (see Fig. 1). It was shaped by partition walls and curtains that allowed the participants to isolate without losing audible connectivity with the rest of the media lab. The office space was divided into a work area and a rest area, offering different work modes. The work area consisted of a table, a table lamp, and an office chair and the rest area of a small sofa and a little sideboard. The technical output devices (actuators) of the AIS were subtly woven into the work environment. Colored light of three longitudinal RGBW LED lamps was reflected by the white partition walls and the table lamp was also accessible for data representation. Sound came from two speakers fixed to the partition walls but was also perceivable through vibration by contact speakers mounted underneath the table and the sofa. A ventilator placed on the floor was also technically controllable to emit information via airstream. To shift the perception of environmental information from the periphery to the center of participant attention, the activities of the technical devices faded in and out, **transforming from incidental office furniture to tools of data representation**.

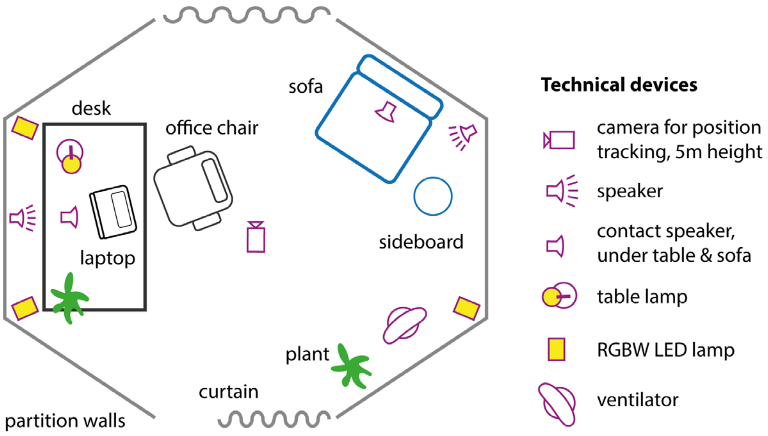

Fig. 1. Floor plan of the research facility with a work and rest area.

4.2 Sensor-Actuator System

To design an AIS for the representation of human behavior and arousal, we developed a Sensor-Actuator System. Using the software MaxMSP, we set up a technical environment that allowed the **acquired data streams to be mapped to physical parameters in real time** and the signals to be recorded for later analysis. Behavior and arousal were captured by sensor measurements of:

- position tracking (camera-based color tracking of red hat: x, y coordinates),
- head movement (3-axis accelerometer fixed to red hat: sum of delta values),
- wrist movement (3-axis accelerometer sensor in *E4 Empatica* wristband: sum of delta values),
- heart rate (pulse sensor in *E4 Empatica* wristband: beats per minute (bpm).

Some sensors were wired, others transmitted data via xBee or bluetooth wireless protocols. The measured data was processed, and different actuator parameters were controlled according to a rule-based system:

- light by different types of lamps (brightness, hue, saturation, interval),
- sound by speakers (source, volume, audio effects),
- vibration by contact speakers (source, intensity, interval),
- and airflow by a ventilator (strength, interval).

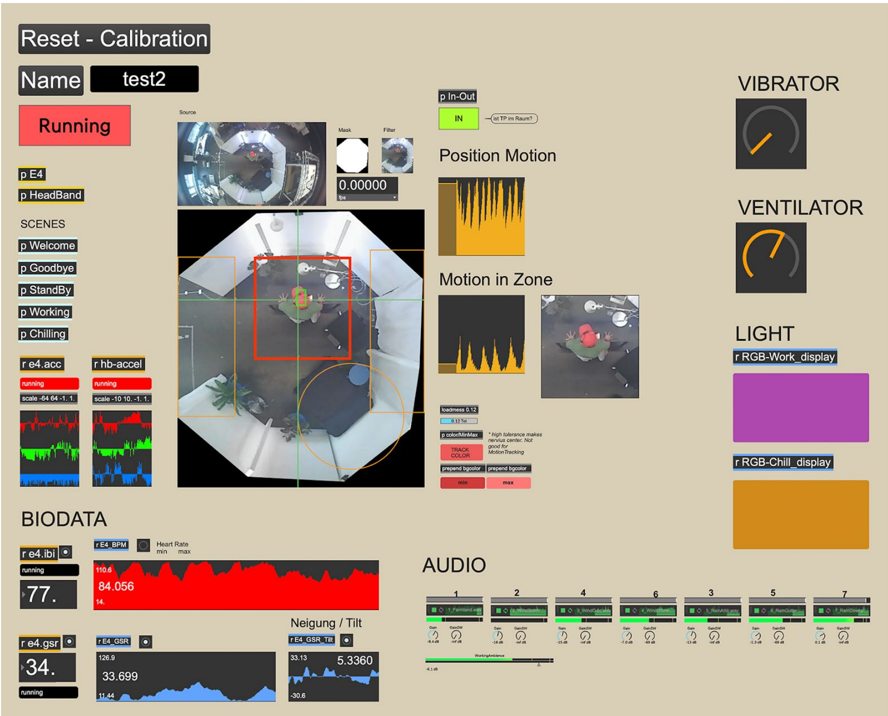

Fig. 2. Screenshot of MaxMSP control interface with camera tracking view, input signals and output controls.

Fig. 3. *Empatica E4* wrist sensor for measurement of heartbeat and acceleration. **Fig. 4.** Red cap with technical components: Arduino Lilypads, accelerometer, and battery.

4.3 Ambient Information System

The focus of the design developments was on the AIS, the **data mapping choreography**, on how the measured sensor values are translated into physically mediated and spatially integrated representations. We iteratively developed and tested two different types of data representations. The first type was **causally recognizable feedback**, displaying measured signals in real-time. It was applied to signals of physical motion and biodata measurements and therefore an indicator of physical activity and somatic (possibly psychophysiological) reactions of the participants. We used it to generate participants' awareness of physical and psychological reactions to different work processes. The second type of ambient data was based on **atmospheric compositions that built up or degraded over time**: Weather sounds built up over time in the work area, while slowly decaying music sounded in the rest area. These changes were based on long-term behaviors of the participants, such as sitting still for a longer period. They were not intended to provide direct feedback, but to proactively influence or even patronize participants.

For the technical implementation, we developed a **rule-based system** that triggers the ambient events. It was based on conditions, thresholds, and value ranges that were defined or scaled based on preliminary tests we conducted with subjects. For example: If the participant is in the work area and the heart rate is above 85 bpm, start to increase the intensity of the contact speaker according to the bpm (85+).


Fig. 5. *Participant wearing the red cap in the work area with colored light displays*. **Fig. 6.** *Participant wearing the red cap in the rest area with colored light display, fan and plant*.

The AIS was divided into different spatial areas: entrance areas, work area, rest area, and intermediate area (see Fig. 2). The **entrance areas**, in combination with the intermediate area, were used to determine whether the participant was present in the room. Accordingly, a greeting tone was triggered when the participant arrived and a farewell tone when s/he left. Upon entering the **intermediate area**, the participant only triggered quiet city sounds slowly fading in. It was offered as a hidden area without AIS features.

In the **work area**, the heartbeat was presented in the form of colored light (two RGBW LED wall lamps behind the table), heartbeat sounds, and vibration of the table. The light pulsed in blue-green color at low heart rates and turned red as the frequency increased, with faster flashing intensified by an increase in color saturation. The heartbeats also became increasingly audible, and the vibrations of the table became increasingly noticeable as the frequency increased. Pretests with different subjects were necessary to adjust the parameter settings to a middle ground between detectability and tolerability. This approach represented the current pulse, thus acted as "positive feedback" and was not intended to have a calming effect on the person. Over a period of twenty minutes, a thunderstorm built up hardly noticeable: It started with soft wind sounds, increased with rain sounds, culminated with lightning and thunder, and remained at this intensity level until the person left the work area. The lightning was accentuated by the flickering of the table lamp and the gusts of wind were physically felt through the fan. If the participant left the work area early, the absence time (multiplied by a factor of 12) was subtracted from the presence time and the buildup of the thunderstorm was reset accordingly. This staging served as a patronizing request from the room for the participant to finally take a break. Regardless of heartbeat and dwell time, arm movements and head movements triggered different water sounds that integrated with the rainy weather sounds.

In the **rest area** meditative music was played, different pieces of music in varying order. Each piece of music was visually underlaid with the RGBW LED wall lamps by a different color spectrum (e.g., green-blue, orange-yellow). The heartbeat was represented by color changes between the poles of each color spectrum, with colors slowly fading at low bpm and flashing without progression at high pbm. We implemented this alternative pulse representation to compare with that in the work area. Like the building thunderstorm in the work area, a temporal change came into play: After ten minutes, the music became increasingly distorted by a sound effect and the fan began to blow if the participant did not move. This staging patronized the participants by asking them not to remain idle in the quiet zone. Participants were to realize that they could stop the increasing process by moving their head and arms. The contact speaker mounted under the sofa was activated by the movements to make causality more apparent.

5 Evaluation Design and Data Analysis

To evaluate the research setting, we developed a **mixed-methods approach** following a standardized evaluation process with invited participants. Quantitative sensor data (biofeedback and camera image) were collected, visualized, and used to validate qualitative data, which is the main source of knowledge production in this work. In order to capture subjective experiences, the participants were asked to complete an online questionnaire during the experiment followed by an interview. The interviews were analyzed using Qualitative Data Analysis (MaxQDA) and the patterns were reviewed with the online diary.

We invited **22 participants**, taking into account diversity as much as possible. The gender sampling was equal (11 females and 11 males) and the age groups – which were divided into blocks of 10 years each – were sufficiently covered by the selection of participants: 3 participants of the age group 15-24, 7x 25-34, 5x 35-44, 3x 45-54, and 4x 55-64. Diversity of professional background was neglected as we mainly tested with colleagues from our university who are mainly working in the field of culture, design and humanities. All participants were asked to give consent to the use of **anonymized data collection** and camera recording. The anonymized data is stored on the database SWITCH, based on the Data Management Plan agreed on with the Swiss National Science Foundation.

All participants were introduced to the experiment according to a **standardized protocol**. To level personal somatic and psychophysiological variations, they were calibrated with a three-part exercise wearing the wristband. To determine the physical state of relaxation, they had to lie down to yoga music. To reach climax, they had to do some fitness exercises and to measure psychophysiological arousal, they had to watch a thrilling video sequence. The **duration** of the experiment was set at one and a half hours and was designed to allow habituation and learning processes to occur. To be able to investigate the shifts of attention for the AIS, we asked participants to perform **everyday tasks on their personal laptop**. They should be busy with something, but also perceive feedback, be disturbed or pointed to something in different situations and phases of concentration. We also asked them to use both the work and rest area and allowed them to talk on the phone or leave the room for short breaks.

To be able to investigate which embedded interfaces and AIS designs were recognized by the participants themselves, Test Group A was not given any **explanations about the features and functionalities** of the AIS beforehand. Test Group B was told that the colored wall lights, speaker sounds, and vibrations of the table in the work area represented their heartbeat, and that the movement of their left arm and head produced water sounds. They were also made aware that the vibrator under the sofa and the fan in the rest area were responding to them. Nobody was made aware of staged temporal changes that depended on the length of stay or other behaviors. The division into these two groups made it possible to elicit the influence of prior knowledge on experimentation and sense making processes.

Since the experimental facility was spatially separated from the rest of the lab only by partition walls, the participants were not completely isolated from other people working in the lab. This allowed us to study whether they considered the display of their somatic signals in the semi-public space to be problematic in terms of **data privacy**.

The camera image used for position tracking was recorded as well as the heartbeat. The sensor values were visualized in a dashboard and synchronized with the video recordings. However, these **quantitative methods** were not statistically evaluated in this experiment, but only used heuristically to contextualize and verify the subjects' statements about their user experience.

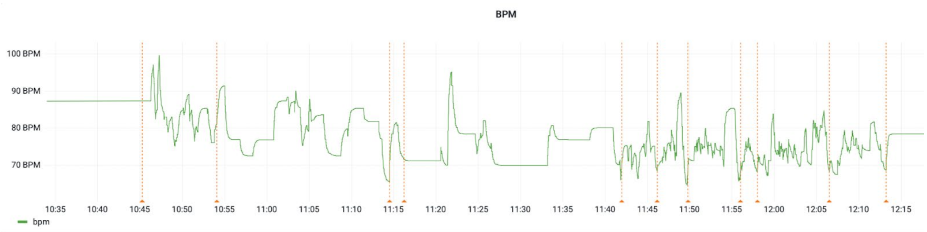

Fig. 7: Data set of a participant's heart rate during the 90-minute experiment, including markers for diary entry assignment.

To obtain feedback during the experiment, participants were asked by an acoustic signal to make an entry in an **online diary**. This was triggered at 20-minute intervals and for particular behaviors, for example, if the participant did not move for a long time or if his heart rate exceeded 90 bpm. It contained three standard questions about their mood, the environmental influence on their mood and their productivity, that could be rated with a 5-point Likert scale. The repeated questioning served to generate a quantitative picture of the course of the dimensions surveyed (pulse survey).

Finally, we conducted guideline-based **interviews** that allowed us to gain insight into the reality of the subjects. The questions covered topics such as the condition of the day, tasks performed, influence of the responsive environment on the state of mind, characterization of the environment, the perception of the AIS interaction modes, and the use of the setting as a workplace. The questionnaire as well as the interviews were conducted and recorded in German, transcribed and translated into English at the time of analysis. The translations were validated by means of the 4-eyes principle in order to avoid translation errors and later prepared for qualitative data analysis using the MaxQDA software. Category-based content coding [12] was initially deductive, with inductive categories adding to the system as the process progressed. The topics of the interview questions were expanded by the following constructs: affection, possible areas of application, privacy, description of room functions. To ensure that no narratives were lost, all interviews were re-coded in an iterative process. A compiling summary of each category was provided for the final rendition of the reactants' realities. For the comparison of group A and B and demographic factors such as age and gender, the corresponding categories were also assigned and the content summarized per group. To find key statements, keywords such as space, character, productivity, well-being, system and design were searched across all transcripts.

6 Findings and Discussion

The study has produced interesting findings, which we would like to present and discuss in this section. According to the defined focus areas, we divide it into the general part Work Environment with an Embedded Ambient Information System (6.1) on the one hand, and the design-oriented part Embedded Ambient Interfaces & Data Mapping Design (6.2) on the other hand. Quotations from the transcripts are reproduced below in parentheses with the initials of the interviewee and the paragraph number, e.g. (TK; 13).

6.1 Work Environment with an Embedded Ambient Information System

We asked the participants how they felt before the experiment and what they anticipated. They mostly came without great expectations and wanted to use the time to work. Participants who were very focused on their work hardly perceived correlations between their actions and the environment and were even able to **mentally escape** the patronizing temporal developments (storm and distorted music). Even though most participants were doing administrative computer work, they were very immersed and an AIS for a work environment must therefore be designed with appropriate emphasis. Since we did not want to adjust the sometimes subtle design appearance of the AIS during the experiment - e.g., by using more intense light and louder sounds - we decided to inform a second group B in advance about the features and functions of the AIS. In addition to insights into the recognition of the AIS, this should lead to findings about the **willingness to experiment**, use and acceptance during the work process. **Learning and habituation processes** therefore occurred at different times depending on the group: Participants in group B already used interaction and reaction patterns in the first half of the experiment, whereas about half of group A did not notice them until later in the second half. It would be good to repeat the experiment over a longer period of time to check the presence of the AIS across work processes with different concentration phases.

Due to the discrete integration of the sensor technology in the cap and wristband, the test subjects hardly perceived the wearables as measuring instruments. As intended, the majority of participants described the Office Space as clean and neutral. The AIS was mostly classified as an ambient tool at the beginning. However, as the experiment progressed and the stimuli intensified, participants increasingly **characterized the space** as uncomfortable, noisy or repulsive: *"The room, it wants to get rid of me now. It just* *wants to annoy me"* (BT; 21). Four participants had already worked with sound tools to increase their productivity and were therefore open to the basic strategies of the installation. The feedback was probably also unexpectedly positive for this reason and there was less spontaneous reflection on the artistic concepts than on possible applicability. Since we conducted the research with colleagues from our university, the familiar environment certainly also had an influence on **acceptance**: *"But it's also, it's also special as a laboratory arrangement somehow. But it also doesn't matter what I do in it. It's still somehow within the bounds of what's okay"* (LF; 83).

The approach of increasing one's own **productivity** with an AIS was mostly rated positively. *"B: I can imagine using acoustics or light or basically colors or space, climate, atmosphere, to create a room in which one can perhaps learn better or work more concentrated in any case"* (SH; 55-59). However, about three-quarters of the participants wished to be able to **customize** the AIS individually and situationally, for example, to be able to activate only the sound or to use an intelligent version: *"And I guess at a certain point, you can also maybe it could be more personalized, and like kind of, it could also be some sort of a, how do you say, some machine learning system that is a little bit more organic, the way in which those breaks are set, rather than being fixed on some certain parameters"* (JP: 44). The dubbing of one's own heartbeat was rated as a potentially valuable tool, but was also criticized in terms of **sensitivities**: *"And I think, I don't know, I find the sound of heartbeat something fundamentally not calming, but something that tends to stress me out"* (NS; 11). One participant noted that certain tasks could also be completed more successfully under stress, depending on the situation, and that in terms of productivity it is not always just a matter of feeling particularly good.

The analysis of the online diary (pulse survey) also yielded interesting results concerning mood and productivity (see Fig. 8). Given the sample size, it is difficult to draw meaningful conclusions, but the tendencies observed could be compared to the qualitative data of the interviews. **Mood and environment mood** did not show much of a variance in the purely descriptive statistics. After the first measurement point, productivity showed slightly increased values at the second and third measurement points and decreased again at the fourth. In the interviews, participants also retrospectively reported higher productivity in the middle of the experiment than at the beginning and end. Many participants stated that they had to get used to the situation at the beginning, which would make the lower value in the figures plausible. The noisy environment, often described as annoying, could be understood as the reason for the lower productivity scores at the end of the experiment.

Table 1. *Descriptive statistics of the total values of the online diary (pulse survey).*

Online Diary (N=21)	*M*	*SD*
Mood 1	3.9524	.97346
Mood 2	3.8095	.81358
Mood 3	3.8571	.85356
Mood 4	3.6667	.65828
Environment Mood 1	3.2381	.94365
Environment Mood 2	3.5238	1.07792
Environment Mood 3	3.3810	.92066
Environment Mood 4	3.4286	.74642
Productivity Level 1	3.4286	.74642
Productivity Level 2	3.4762	1.07792
Productivity Level 3	3.4762	.87287
Productivity Level 4	3.3810	.74001

Notes. Numbers 1-4 show the measuring time of the pulse survey.

Since the experimental setting was shaped by partition walls and curtains only, the audio biofeedback of the participants was perceivable for the rest of the media lab's staff. When being asked, most participants were not worried about their data being audible for others. It was hardly considered critical, since they did not expect others to understand their **semi-publicly displayed** biofeedback. However, there were also situations in which the acoustic feedback was experienced as unpleasant in a social context: One participant recognized the increase in her biofeedback when preparing for an uneasy phone call. She was uncomfortable that other people in the media lab and, depending on the situation, even the person on the other end of the phone line could detect her arousal.

6.2 Embedded Ambient Interfaces & Data Mapping Design

In this section, we would like to focus on the design-based aspects, highlighting the effect of the different AIS media (6.2.1), their parameter settings (6.2.2), and distinguishing findings about subjects' perception and interpretation of spatio-temporal (6.2.3) and causal interactions (6.2.4).

Furnishing as Information Mediator

As **physical components** for the AIS, we chose a table lamp, three wall lamps, two speakers, two contact speakers, and a fan. The furniture and devices were used as channels to display information about the position, movement, and personal heartbeat of the participants. They could also be **combined and compared.** The heartbeat, for example, was represented in the work area by colored lamps, speakers and a fan and allowed to compare the user experience of the different channels. Nevertheless, the patricians of group A hardly perceived this multimedia biofeedback or did not identify with it. Once recognized, the acoustic data representation was perceived as most pleasant. The vibration transmitted by the contact speaker under the tabletop was also rated positively, as it was applied very discreetly. In comparison, the data visualization via colored light with the wall lamps was perceived as rather disturbing and was not judged to be purposeful. Four participants, however, reported that they were able to mentally block out the lights very well even though they were located behind their computer screen.

The physical AIS components were also **used scenically**. The flickering of the table lamp during the thunderclap and the gusts of the fan during violent wind noises support the immersive experience of the acoustically represented thunderstorm. These interventions were designed to explore strategies to influence participant behavior and were not primarily intended to improve well-being. The choreographic interplay was understood as intended by most participants and contributed to the intensification of the narrative. As mentioned above, the reactions varied: some were so engrossed in their work that they could even block out a thunderstorm, for others it felt very cozy, and still others were annoyed and looked for a non-responsive place.

In terms of **interactions with the devices,** women were more eager to experiment than men. Even plants, which were understood as possible electronically enhanced interfaces, were investigated:

AM: "*Exactly. So, I also moved my hand in the middle of the room or looked under the table or touched the plant.*"

I: "*Did you also play?*"

AM: "*Yes, but I don't think anything changed there. There's nothing connected to the plant like that. But yes, I wanted to see if maybe something is hidden somewhere*." (AM; 37-39).

Although detailed group comparisons were made among age groups, we could not identify any differences of behavior and attitudes based on age groups.

Mapping Choreography: Parametric Information Design

The development of the research setting required many design decisions and iterative optimization processes. After choosing the appropriate tools for conveying information, we had to design their parameter settings. Pretests with different people were necessary to adjust them to a **middle ground between detectability and tolerability.** The vibrator under the chair, for example, was perceived as unbearable at high intensity, but as pleasant and supportive after the right dosage. In the end it was set so subtly that the participants were sometimes not sure whether the vibration was transmitted via the furniture or the air.

The design potential when dealing with parameter settings can also be illustrated by the data visualization of the heartbeat using colored light. We implemented two different pulse displays in the rest area and the work area to compare them. In the work area, faster blinking for higher pulse was accentuated by increasing the color saturation (white-color), in the rest area by increasing the length of the fade between two colors. Such design nuances were never consciously perceived during the timespan of the experiment and the computer work. However, these types of design considerations are valuable tools to **improve the aesthetics** of the user experience and to scale the presence of data distribution.

The **information mediator fan** would probably have been better camouflaged in a hotter environment but would also have made itself noticeable there by independently changing the speed. The intense wind gusts emitted during the storm were perceived as very disturbing and contributed significantly to the participants leaving the work area. The gradual increase in wind flow after a period of physical inactivity in the resting area was also found to be disturbing, and no one could see the causal relationship between their head and arm movements and fan activity.

Interpretation of Spatio-temporal Assignments

Based on personal preferences and according to the work to be done, the participants decided to work at the desk or on the sofa with background music or to alternate. The medial change of mood in the two zones was recognized by all test persons. Some participants became aware of the intentions and patronizing attitudes of the **room's dramaturgy**: *"The room wanted me to go!"* (JB:23). In one case, the scenic change was judged as too fast and causal, indicating that the parameters "responsivity timing" and "intensity of responsivity" are important design issues. *"When you're just looking out for a moment or just going here or there for a moment, the switch, so it's great that that works, but then it's a bit unnecessary that it switches immediately like that and then a second later it switches back again."* (FG; 32-35). In general, the **atmospheric sounds** of nature in the workspace were found to be more pleasant and conducive to productivity than music. We received feedback that the *"rain sounds from outside"* made people feel like they were in a protected, cozy place, and thus immersed in the staged narrative. *"But when the thunderstorm was, I kind of already imagined myself in a mountain hut like that."* (JS; 15).

The responsive staging of the zones sometimes led to discomfort and frequent changes of location: Three participants discovered the intermediate zone with the quiet city background sounds as a place of rest for themselves. They avoided the patronizing character of the installation and customized their situation: *"Yes, or even when I have to think big thoughts that I can have very quiet, for example. Then I go back to the table, but that was too exhausting for me. Then I looked for something quiet in the middle of the room"* (LF; 27).

Interpretation of causal relationships

The experiment began with us telling participants that the room responded to them, but not how (Group A). We wanted to find out what causalities they could identify in their interactions. The implemented biofeedback for the heartbeat was partially suspected, but not confidently related to itself. *"I just always found this heartbeat a bit strange, because there I didn't know if it was me or is it someone else."* (NB; 5) In group B, some attention was paid to it and the tool was considered quite interesting, as an occasional, somewhat unconscious form of control of one's own psychophysiological state.

In the work area real-time sound effects of head and arm movement were designed to indicate restlessness. They were meant to make people aware of (strange or unnecessary) movements they perform during the work process. No participant detected this form of causal feedback, unless they were told (Group B). Even in Group B, they did

barely consciously interact with it. We assume that it was a design issue, that the triggered water noises were too neatly integrated into the weather background sounds. Design adjustments would be interesting to be studied in a follow-up experiment. One participant from group B however stated that she had used the arm and head movement to express outrage. Instead of screaming she used the tool to unload frustration during the work process. This kind of participant feedback is very valuable to create new design approaches.

In the rest area we implemented that the staging of the increasing music distortion can be stopped by moving arm and head. It was a form of paternalism that asked participants to move more (not fall asleep). Since we did not explicitly mention this precise form of interaction even in Group B, no one recognized it. Such forms of interaction would have to be observed and functionally adapted over a longer period of time.

7 Conclusions and Outlook

With this study, we present results on user experiences, appropriation processes, well-being, productivity, and data mapping strategies in a work environment with an ambient information system embedded in the furnishing. The paper concludes with **suggestions for adaptation of the experimental setup as well as an outlook** on further research approaches.

The quantitative methods were not evaluated statistically in this experiment but were used to verify the participants' statements. We made this decision because we had collected little information about the **participants' activities** and could not assign their influence on the biodata. In a follow-up experiment, participants could play a game in which different situations are trackable and measurements and behaviors can be contextually assigned. Also, the experiment **length** of 90 minutes turned out to be rather short for appropriation processes. We suggest developing a mobile sensor-actuator setting that could simply be set up at test subjects' home offices and studied over a longer period of time. Although the **sampling of participants** was sufficiently heterogeneous in gender and age, we mainly recruited colleagues for the survey. In order to obtain more valid results, participants from outside the university with different backgrounds should be recruited. To study to what extent **data privacy** would become more critical if all persons in an open-plan office could understand each other's biofeedback, we suggest equipping several workstations with the same AIS and have several participants work in them at the same time.

In order to derive further **design principles** for the AIS, the different media and their parametric settings would have to be examined individually in a next step and a distinction would have to be made between direct biofeedback and influencing strategies. Although acoustics were judged best as spatially distributed feedback, vibration in everyday objects also seems promising. However, with the right parametric settings and situational integrations of information into furnishing, we continue to see opportunities to work with lamps and fans. The contextualized recognition of ambient information, on the one hand, and the disruptive influence during the work process, on the other, requires fine-tuned design and handling adjusted over time. In order to identify the critical features and contexts and to identify standard settings for different work situations, a Graphical User Interface for customization could be provided to the participants in a follow-up project.

The *Periphery* experiment was created as part of the *Paradigms of Ubiquitous Computing* artistic research project. It is partly playful and challenging, but partly has a claim to concrete applicability. Because the AIS under study encompasses multiple approaches in parallel and the results are based on feedback from only 22 participants, follow-up projects are needed to produce quantifiable results. Nonetheless, the results open up an exciting field of perspectives for designers and work psychologists, and detailed insights into design processes and strategies for embedding an AIS into furnishing.

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