Design Requirements for Ambient Display that Supports Sustainable Lifestyle

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ABSTRACT
People are ready to change themselves to adopt more eco-friendly habits such as conserving electricity when they are aware of the possible problems of their lifestyle. In this sense, *ambient display,* which users experience occasionally without its interfering with their primary tasks, is well suited to provide the feedback of their personal activities in a more subtle manner than direct information presentation. We present the results of user studies with two ambient displays in different visualization styles. Participants showed diverse usage behaviors of ambient displays according to their motivational level of sustainable lifestyle. In addition, iconic metaphor of eco-visualization can trigger more emotional attachment while indexical representation helps retrospective functions. Finally, we suggest design requirements for ambient displays that support different stages of persuasion from raising awareness to motivating to change behaviors and to maintaining desired habits.

Author Keywords
Sustainable design, persuasive technology, ambient display, behavior change, eco-visualization

ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION

Persuasive Technology is technology that is designed to change the attitudes or behaviors of its users through social influence without coercion [12]. In the past few years, a number of HCI research have investigated how to motivate people through persuasive technology, especially in the domains that are widely referred to sustainable design [8, 9, 13, 14, 17, 19, 20, 21, 26, 27]. However, there are several neglected aspects in designing persuasive systems—individuals' different stages toward sustainable lifestyle and the effective visualization styles as feedback.

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Behavior change happens along the several stages including the *awareness of surrounding problems*, the *action of the desired behavior*, and the *maintenance of the change* [7]. Procedural change needs different techniques at each stage for the design of persuasive media. A current research suggests *motivational framework* that provides different goals and recommendations to people according to their reached stage [15]. However, many of interactive systems have less studied the appropriate media, design strategy and user interaction at the stage that the system is targeting.

Popular forms of persuasive media include mobile displays [13], website [26], and physical objects [14, 19]. No matter what the destinations of persuasive media are, HCI researchers have empathized persuasive feedback through the visualization of sensed data. For the specific domain of sustainable living, many have suggested *eco-visualization* as a means of persuasion [17, 27]. However, they have not yet proven what are suitable forms (e.g., text, diagrams, pictures) for the eco-visualization of sensed data. The empirical evaluations of the effectiveness of persuasion, especially comparative studies of different visualization techniques, are rare.

This paper attempts to address the previously neglected topics in sustainable design. Focusing on the early stages of persuasion that requires *awareness of the surrounding problems*, we assume that ambient display can serve as a suitable form of persuasive technology that senses activities of users and provides real-time feedback without causing interference with their primary tasks. To support this assumption, we designed two ambient display systems, and compare of effects of different visualizations on multi-stage persuasion. Our investigation attempts to answer to the following two research questions:

R1: How do people experience ambient displays as a persuasive medium differently according to their motivational level and the consciousness of their problematic behaviors?

R2: How do the representation styles of eco-visualization affect users' perception, awareness of their own activities, and their potential behavior change?

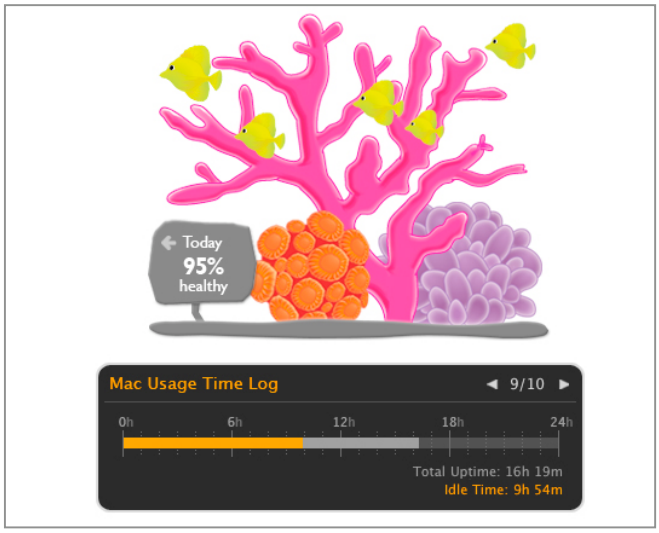

Figure 1 & 2: Coralog and Timelog

First, we explore the background of persuasive ambient display: theories and suggestions by HCI researchers and behavioral psychologists, and the potential of ambient display for persuasive usages. Next, we describe the empirical research with the Mac OSX widgets *Coralog* and *Timelog* (Figure 1 and 2): system descriptions, methods, and the results of a semi-longitudinal user study of with fifty two participants for two weeks. Finally, we suggest design requirements for the ambient display embedding eco-visualization that supports sustainable lifestyle.

PERSUASIVE AMBIENT DISPLAY

We review current sustainable design practices and theories of behavior change from psychology and the definition and design dimensions of *ambient information display* [30]. Connecting the two themes, we argue that the characteristics of ambient displays are suitable for persuasive design.

Early Stages Toward Sustainable Lifestyle

Current Suggestions for Sustainable Design

For the past few years, the HCI and interaction design has enormously devoted to the research of sustainability. Diverse research foci exist including the general notion of sustainable design [1], a macro-study on the context of green lifestyle [35], implementation of a working system [13], a theory-driven design strategies [4], and a suggestion of a new perspective from arts [9].

Woodruff et al. proposed *personal choices* and *changing circumstances* as the area of what HCI research can support, after searching for the motivations, practices, and obstacles of people with pioneering sustainable lifestyles [35]. These researchers admitted that changing circumstances were challenged by the lack of social and institutional infrastructures. Alternatively, they presented realistic and specific design implications that support *personal* green choices focusing on specific areas rather than collective and generalized guides. Criticizing the traditional HCI evaluation methods for sustainable design, DiSalvo et al. presented an alternative assessment that focused on "how an individual's behavior is called into questions and accounted for and how people make sense of the experience," and argued that "the design sparks reflection about one's own behavior [9]." These two claims necessitate the first research question—whether ambient display can provoke an individual's awareness of a specific and problematic environment that otherwise could not appear visibly.

Self-realization to Become a Green Person

HCI researchers draw theoretical foundations from behavioral psychology [4, 15], where many scholars have studied the factors, motivations, and stages of persuasion that lead to an individual's modifications to her desired status [5, 22, 28].

Exploring the mechanics of intentional behavior change, Prochaska et al. suggested a model of *stages of change* [31]. According to them, people experience several cycles of the five stages—*precontemplation, contemplation, preparation, action* and *maintenance*—until they finally terminate addictive behaviors. The first stage, *precontemplation*, is where individuals are unaware or "underaware" of the problems resulting in no intention to change behaviors. In the next stage, *contemplation*, they are aware that a problem exists, but not committed to take action. Moser et al. addressed the *internal (psychological and cognitive) barriers* that prevented a person from *understanding the issue (causes) or seeing the relevance of climate change impacts or solutions to one's daily life* [25]. Such psychological research indicates that many people still remain in the first two stages, whose processes include *consciousness raising* and *environmental reevaluation* [31]. We infer that people in those pre-action stages need education to increase the awareness of the problems and to motivate the behavior change.

De Young presented *internal* source for behavior change toward an environmentally friendly lifestyle. For the initiation of internal motivation, he stressed the importance of *information* as a behavior change *technique*, which included *direct experience, personal insights* and *self-monitored feedback* [7]. From this notion, we induce again, the importance of self-discovery and awareness as the first step of behavior change through feedback.

By synthesizing these theories driven by behavioral psychologists and the suggested design implications in HCI, we conclude that changing habits to environmentally friendly manner is not easily accomplished. Becoming green is not a goal-oriented task to be completed in a given time, but a gradual and intangible transition of lifestyle. Therefore, gentle and kind initial approaches to a single person are necessary, especially when she is not motivated and not well aware of the effects of her everyday activity on environmental changes.

Definition and Design Dimension of Ambient display

Pousman et al. used a term, *ambient information system* as they inclusively referred to screen-based ambient display. According to their definition, ambient information systems 1) *display information that is important but not critical*, 2) *can move from the periphery to the focus of attention and back again*, 3) *provide subtle changes in the environment*, and 4) *are aesthetically pleasing*. They also presented four design dimensions of ambient systems [30].

- *Information capacity*: the number of discrete information sources that a system can represent.
- *Notification level*: the designer-intended level of alert. This dimension decides the "ambient-ness" of the system.
- *Representational fidelity*: the level of abstraction of raw data. Borrowing the concept of *sign* from semiotics, three categories are introduced.
  - Indexical: direct representation
  - Iconic: immediate matching through related metaphors
  - Symbolic: completely arbitrary and abstract symbols
- *Aesthetic emphasis*: the relative importance of the aesthetics over utility.

Bridging Ambient Display and Sustainable Design

Friendly and non-intrusive implication is crucial in persuasive design, because it can be a starting point to a sustainable life and hint acceptable and affordable actions to take between the ideal eco-life and contemporary busy days. In this sense, ambient media display shows the possibility of a pervasive and amiable system that makes users become aware that their ordinary actions are related to environment issues. Consolvo et al. [4] suggested eight design strategies for technologies that support behavior change: *abstract & reflective, unobstrusive, public, aesthetic, positive, controllable, trending/historical and comprehensive*. We find much overlap between these design strategies and the characteristics of ambient display, which conceptualizes four conditions of persuasive ambient display as following.

- **Information from a focused domain:** Persuasive ambient display should have low *information capacity* conveying only necessary and critical information of a specific activity or domain. If a user needs further knowledge beyond the conveyed information by default, a system occasionally is coupled with complimentary information and thus satisfies the strategies of *trending/historical* and *comprehensive*.
- **Low distraction for checking:** To be truly pervasive, *notification level* should be minimal and *unobstrusive*. The system should be hidden enough for a user to *ignore* while focusing on their primary task and become visible only when she desires to check.
- **Visual appeal:** This condition is compatible with the design strategy *aesthetic*. Highly aesthetic presentation triggers users' interest and deep engagement. We clarify the meaning of "aesthetic" here. For us, the design dimension *aesthetic emphasis* is not only set by designers' intention [30], but also experienced and valued by users. We do not believe that aesthetics if simply achieved by mimicking artists' work as discussed in other research [11]. Moreover, aesthetics is not a contradictory or decorative concept against the functionality of information conveyance, which is apposed to [33].
- **Representation through iconic images:** The *abstract & reflective* design strategy suggests using *data abstraction rather than row or explicit data* [4]. The representation style of many previous design projects is also iconic or abstract images [8, 13, 14, 18, 19]. The encoded data allow users to create their own stories and have emotional attachment [8]. However this indirectness and ambiguity of abstract images provoked users' frustration and the needs for the more accurate data [13]. We will speculate on this issue in the following section.

NEEDS OF COMPARATIVE EXPERIMENT

Literature review on information visualization and persuasive technology did not allow us to choose which *representation fidelity*—indexical or iconic—would be strategic for behavior change. We articulate why we performed a comparative study with two different styles of visualization—abstract images vs. direct representation.

Eco-visualization [17] aims at revealing energy use in order to promote sustainable behaviors or fosters positive attitudes towards sustainable practices [27]. The representational styles (look-and-feel) of eco-visualization used are typically either close to scientific visualization clearly showing the accurate numerical data of consumed energy in text or conventional bar and pie charts, depicting the accurate numerical amount of consumption (*pragmatic visualization* [27]) [e.g., 26] or too abstract and metaphorical images that do not directly relate to the environmental agenda (*artistic visualization* [27]) [e.g., 17]. In spite of the numerous examples of eco-visualization in HCI and art, researchers have hardly performed evaluation on different representation styles.

Ambient display researchers have compared the effectiveness of text and image empirically [28, 29, 34], through which it is found that highly graphical ambient displays enable users to recall greater amount of information. However, the results are not suitable to be applied to designing *persuasive* ambient display, since the objective and method are different. In contrast to the previous research focused on measuring communication ability through lab-based quantitative tests that ask subjects to recall what they visually perceived, our purpose of comparative study is to explore the perception and the awareness of individual habits in a real context where the system will be used.

One recent research project on the evaluation of an ambient display embedded in a mobile phone designed for behavior change revealed the participants' ambiguity about the

visualization style. Interestingly enough, they showed almost equal preference between iconic and numeric representations. When they were provided with abstract images, they desired to see numerical data in order to review both real-time status and past activities more accurately [13].

We found similar reaction to the iconic images from our preliminary study on Coralog [20]. After we first implemented the prototype of Coralog, we performed a study with six regular widget users for one week. One of the purposes of the study was to obtain feedback on the visualization and the function of Coralog. All the participants well understood that coral reefs were used to represent the idle time. However, some participants required more accurate data of electricity consumed rather than abstract image: One participant commented "I want to see how much electricity I'm leaking or how my effort to reduce the idle time effects the real world."

In sum, the scarcity of the research on the visualization styles of persuasive media and users' needs for accurate data over abstract images ignited our curiosity. These two reasons motivated us to perform a comparative experiment that evaluates one pair of different representation styles.

EXPERIMENT DESIGN

Besides Coralog (Figure 1), we created one more widget for a comparative study, named Timelog (Figure 2). It represents data in a different visual manner from Coralog. Mac Dashboard itself is an ambient information system that has nested *nuggets* in it [30]. Each nugget satisfies the first two conditions of persuasive ambient display we suggested earlier: *information from a focused domain* within its small size, and *low distraction for checking appearing* by user poll. We describe of the design of the two systems and the methods of the comparative experiment in more detail than our previous publication [21].

Design Description of Two Ambient displays

Sensing the Data of Computer Usage Time

Both Coralog and Timelog render the user's computer usage statistics through two different visual representations. The usage data consist of *total uptime* and *idle time*. Total uptime is the amount of time during which the computer is turned on excluding time spent in sleep mode. Idle time is considered the amount of time that the computer is turned on, but not in use. In our research, idle time was defined as the accumulated inactive time that is detected if no keyboard or mouse inputs occur for more than five minutes.

Mac widgets are designed to load and work only when Dashboard is actively called by a user [6]. Thus we had to develop an additional application that detects computer usage time without user's active involvement. The logging software accumulates both total uptime and idle time when there happens no input more than five minutes and saves them in external files on a daily basis. When a user runs Dashboard, the widget loads the external data and represents them.

Design 1: Coralog

As a metaphor of iconic representation, we wanted objects or creatures that are scientifically related to the real environmental changes but typically hidden from our everyday lives [20]. While searching ecological changes impacted by pollution, we found that coral reefs are one appropriate example. They are currently destroyed by the rapid increase in dissolved CO_2 in the ocean and the elevated sea surface temperatures [16]. Those phenomena are partially caused excessive fossil fuel use, which is the biggest source of electricity in the United States [10].

The effect of environmental change (e.g., an increase in carbon dioxide levels and/or water temperature) yields the following negative results on reef ecosystems. First, coral reefs turn white, which is called being *bleached*. Second, coral skeletons are weakened by higher temperature and subsequent chemical reactions [19]. Finally, reef fish also can be exposed to danger because of the lack of suitable reef shelter. However, coral reefs and fish are likely to recover if the environment anomalies persist for less than a month [35]. We employed the feature of recovery as well as the three major aspects of damage in visualizing real-time data as the instantaneously changing coral's health status (Figure 3).

The logic of coral reefs and fish change that we considered in recalculating the raw data is:

- The ratio of idle time to total uptime decides the condition of coral reefs, which is seen as "n% healthy."
- The coral reef change reflects the performance of the past. For example, if today's ratio of idle time to total computer usage time is smaller than yesterday, the coral reef will become healthier (higher percentage) despite the increased accumulated idle time.

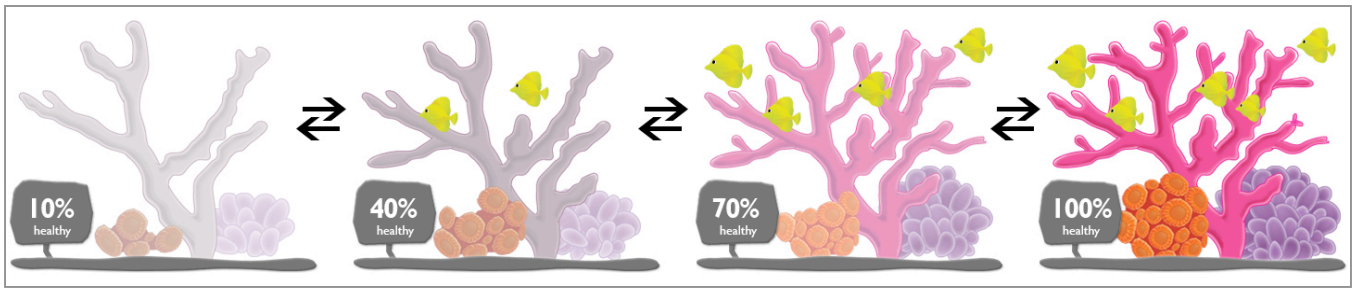

Figure 3. Gradual change of coral reefs and fish according to the health condition

Design 2: Timelog

In contrast to Coralog, what a user sees on Timelog is the original log data without any recalculation or manipulation. For an *indexical* representation we used bar graphs, which emphasize the accuracy of individual values in the length of the bars that starts with the base of zero. Timelog directly shows daily idle time (hh/mm) and total uptime (hh/mm) in bar graphs (Figure 2). On the rectangular-shaped widget, total uptime is shown in a grey bar, above which an orange bar standing for idle time is overlaid. Additionally we put the clear label of numerical data.

History Review Function

We originally wanted a user to simply glances at the real-time status of coral reefs health and a summarized trend of the past week, when calling Dashboard to the foreground. However, from our preliminary study, we obtained the needs of the function of past activity review: "If there is something that shows the historic logs then ... maybe I can see the pattern of my usage" and "I'd like to see my usage everyday, not just 'yesterday', 'three days' and 'a week ago'." To reflect this feedback and the design strategy *trending/historical* from [4], we added buttons for the daily history review up to seven days to the widgets. When a user clicks a button for either previous day or next one, she sees the whole images of coral reefs or bars switching to the selected day.

Participants

We recruited participants through emails, social network sites, and word of mouth. The first criterion is that the subjects should be active Mac OS X users (more than two hour usage per day). We distributed subjects to retain the range of age, gender, and computer usage time even in all groups. A total of fifty-two participants (52% male, 48% female) completed the two-week study in August 2009. Participants represented a wide range of age from eighteen to forty-seven years old and occupations including graduate student, engineer, biologist, and housewife. 92% of participants primarily used their computer at home, office or both places; 61% of participants also took their laptop to random places such as coffee shops, libraries, or friends' house. 71% of participants were heavy computer users who had spent up to five hours per day.

81% of participants had actively utilized and downloaded widgets for fun or practical uses. We randomly assigned these active widget users who had been using Dashboard at least one to three times a week to Group 1 and 2. Twenty-one participants in Group 1 were provided with Coralog; Timelog was given to twenty participants in Group 2. In order to prevent bias from the similar widget experience, we did not choose within-subject method. Instead, we assigned the rest of the participants to a control group, Group 3. They installed only the logging software. Thus, although their usage time was tracked, they did not have any visible clues of their compute usage time unlike the other groups. The third group provided the data for ordinary computer usage.

Method and Process

We combined both qualitative and quantitative methods, which range from online surveys (one prior to the two-week experiment and the other at the end) to the analysis of two-week usage logs, and to semi-structured interviews. We performed qualitative analysis to understand the underneath nature of each person's experience. The primary method used for the qualitative data analysis was a grounded theory [35], which allowed us to draw bottom-up findings based on the direct quotations from the two surveys and interviews and to establish hierarchies and connections among the remarkable findings. The surveys and log data from each participant are for descriptive statistics of the system usage.

1. Pre-experiment Survey: Before they proceeded to install the applications, all participants had completed the survey on a given online survey URLs. The goal is not a description of the context of computer usage per se. Instead, we desired to find their everyday computing habits that may influence the experience and perception toward the tested ambient display.

2. Two-Week Field Experiment: At the beginning of the study, we provided participants with the logging software to all groups and either widget to Group 1 and 2, and let them install the give applications. All participants were not informed where the log files were recorded on their machine until they were asked to send the files to the researchers at the end of the study. During the study, we did not force the participants to complete specific tasks. We expected that the chronologically recorded idle time for the two weeks would provide the evidence of the possible behavior change on the individual level in semi-longitudinal manner. The decrease of idle time while experiencing widgets would reflect the participant's attempt to change her or his habit of energy waste.

3. Post-Completion Survey: At the end of the two-week use period, we sent participants the notification emails of study completion. We requested them to send the recorded two-week log files and complete the final survey. We wanted to evaluate and compare the following aspects of the ambient display through the self-report based survey:

- User experience with the widget, specifically the frequency of usage, explicit or unintentional usage, and the attractive points
- Communication and visibility of the design intention by asking their impression and reaction to the widget
- Perceived quality of visual design of widgets

In addition, we asked about their current awareness of energy consumption. We did not include these questions in the pre-experiment survey because we intended to hide the research goal in order to keep the situation untampered with.

4. Semi-structured Interviews: Finally, we invited five participants who showed distinguishable answers to the surveys. During the in-depth individual interview for twenty minutes over the phone, each interviewee discussed in detail how their awareness and habits had been affected by the use of widget in detail.

RESULTS AND ANALYSIS

At the end of the experiment, we obtained forty-seven complete answer sets (G1=17, G2=16, G3=14) and the interview results with five participants. Each answer set is composed of the two completed surveys and the daily idle time and total uptime during the fourteen days. We present the result of the detailed comparison of the two widgets. Our analysis showed each individual's varied and gradual persuasion toward behavior change and the participants' increased awareness in general as well.

Ambient Display Supporting Gradual Behavior Change

The qualitative analysis allowed us to find individual participant's diverse stages of persuasion. We roughly identified four clusters of the widget users according to the reached level of persuasion—those who 1) showed the level of awareness, but not action of behavior change, 2) tried to modify their habits, 3) already had good habits and used the widget for maintaining their habits, and 4) appeared not to be motivated, who were mainly the Timelog users.

Increased Awareness of Micro-activity

The post-completion survey explained that the participants of Group 1 and 2 had become more interested in their computer usage habits after the study ($t=5.89$, $p<0.001$). While seeing the change of the coral reefs or the bar length, they became curious and tried to find a solution to turn the status back.

"I thought that's a bit sad (…) it reflects back on my behavior using the computer." (P37, Coralog)

A real-time feedback of a single device usage was appeared to be benefit to acknowledge the otherwise ungraspable effects. This supports the first design condition of persuasive ambient display—*information from a focused domain*.

"I never gave a thought to how much electricity my Macbook uses, but it isn't that I don't care. So if an easy-to-understand tool like this can help me track it, I would try and conserve energy." (P14, Timelog)

"Bringing something that is hidden and not so obvious to the front of our minds helps change behavior." (P42, Timelog)

From Awareness to Behavior Change

The more the participants became aware of their micro-activity, (i.e., computer usage habits,) the more they were motivated to change their habits, and finally some of them start action. 30% of widget users (Group 1 and 1) answered that they actually had taken action beyond the stage of awareness; they tried to change behavior explicitly by using sleep mode or turning off more often in order to returning to a better condition. The interview with a user who had not been cared about computer idle time at all strengthened the result. In addition, the log data analysis clarified a single users' trial to reduce idle time (Figure 4).

"My first thought was I wanted to try and reduce my total idle time, or in other words, make use of my computer when it's on and put it to sleep if I'm not with the goal to make the most of the energy I use." (P42, Timelog)

"I tried very hard not to kill coral logs, I constantly kept checking it, it was even stressful." (P36, Coralog)

"Just showing my computer is good. I can actually do immediately." (P3, a Coralog user who had no initial interest in her computer usage habit)

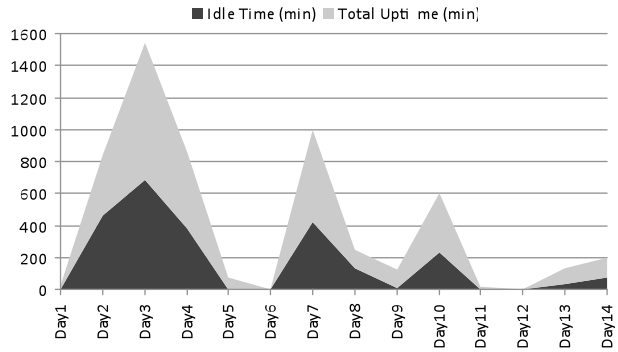

Figure 4. Decreasing ratio of idle time to total uptime of a user (P17, Coralog)

Maintenance of Sustainable Behavior

Participants showed a wide range of interest in their general electricity usage pattern. While 23% did not particularly pay attention to how much they used electricity, another 23% answered they always check electricity bills.

Among these self-motivated participants, those that had practiced putting their computers to sleep mode habitually considered that the widget helped them maintain their habits. Particularly some Coralog users, who were already knowledgeable about environmental issues thought the change of coral log images was intriguing enough to help self-monitoring. Since the idle time of such users was already minimal, the log data did not display significant decrease. Instead, when users monitored their behaviors becoming worse, they immediately tried to return to the desired status (Figure 5).

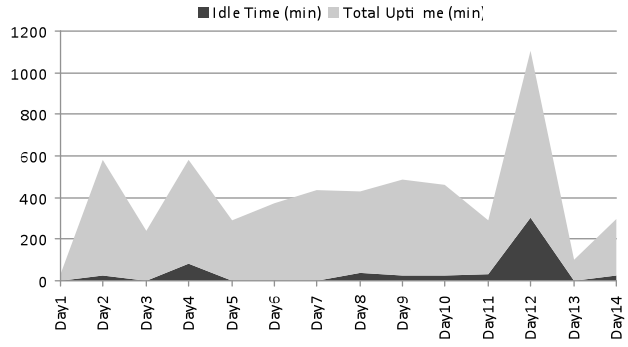

Figure 5. Constant low idle time of a user (P26, Coralog)

Indexical vs. Iconic Representation

Except the provided widget, the two groups had same conditions such as age, gender distribution, and initial interest in computer usage. We first present the results of basic usage experiences including the frequency and reasons of checking systems and the level of attraction. Next, we contrast the two widgets in terms of the aesthetic appeal, visibility of design intention, and functional benefits of each representation style.

Comparison of Usage Experiences

According the self-report survey, among the total thirty-three widgets users, 26.5% run Dashboard more than they did before the study. The trend of frequency of checking the widgets was different according to the widget groups (χ^2=13.504, p=0.001); 52.9% of Coralog users showed the tendency of increase; in contrast, no Timelog users showed the increase of dashboard usage at all.

Two groups showed no significant difference in the primary reason to keep checking the widgets. 70.6% of Coralog users answered that they wanted to check how the computer usage behavior had affected the coral reefs' change. Timelog users also primarily used the widget checking their real-time behavior via either idle time (25%) or uptime (31.3%). 52.9% of Coralog users chose the history review function as the secondary one. For Timelog, similar in preference, history review and merely visual fun are the followed.

There was no significant difference in the intention of seeing widgets between the groups. 58.8% of Coralog and 31.3% of Timelog users tended to see the widgets more intentionally, which meant they run dashboard explicitly to see the widget; others described their habit as more "glancing at" the tested widget additionally while they used other widgets as usual.

60.6% of both widget users expressed their willingness to use the widget after the study. For Coralog users, the biggest reason was that it helped maintain good habits (58.8% of Coralog); Timelog users chose more functional feature of showing idle time and uptime, not necessarily relating to behavior. The willingness of keeping widgets was not significantly different according to usage frequency and the level of awareness.

Two groups did not show a significant difference in understanding the connection between the images and their computer usage time (M(G1)=3.50, M(G2)=4.19 of 5-point scale, p=.162). The satisfaction with the overall visual design was not significantly different either (M(G1)=3.94, M(G2)=3.31 p=.825). However, our qualitative analysis showed distinctions about the perception of the designer's goal and the objectives of usage.

Emotional Attachment to Scientifically Related Images

All seventeen Coralog users grasped that the coral reefs were damaged due to the increase of the idle time. In case of this negative change, 82.3% answered they tried to reduce idle time intentionally to save the coral reefs. The iconic representation helped make a connection between the presented information and the effects on the real world. Conversely, at Chi-square test, although some Timelog users reacted similar to Coralog users, the majority of Timelog users (87.5%) did not express the desire to change their behavior (χ^2=16.70, p=0.001).

"It was an interesting application, but hardly motivating to save more energy." (P28)

Many Coralog users expressed emotional reactions using subjective words such as guilty (P5), frustrated (P8), sad (P37), stressed out, felt pressure (P36), while showing their will to recover the coral reefs.

"I wanted to know why that happened and what I should do to improve my behavior." (P12)

"It reminded me of my impact on the environment at large, and made me slightly more conscious of the need to sleep/shut down my computer when not in use." (P41)

In case of recovery, they used subjective and positive expressions such as happy (P8), encouraging (P17), felt good (22), glad to see (P23), and relief (P34).

Numerical Data for Informative and Retrospective Purposes

43.8% of Timelog users did not show considerable awareness and potential behavior change according to the self-report. The major reason was that they were not able to intuitively match the reported usage time to an exceeded threshold for electricity consumption. Upon the change of the idle time, they did not react emotionally but more neutrally. They perceived the widget as a functional utility for tracking usage time rather than an assistive application for reducing energy consumption.

"It means I've been on the computer a lot. I was impressed that I was on the computer 11 hours one day." (P38)

"It doesn't mean anything to me if I don't know how that uptime and idle time affects either my electrical bill, even Mac battery, or anything." (P25)

"I had considered the log data more as reflection of my daily behaviors. Maybe I would pay more attention to the application if it displays exact amount of energy I consume (comparing to average use)." (P4)

Even though Coralog users became aware of their habits through the abstract images, 35.2% users wanted to see numerical data either in used electricity or monetary expense as a further motivation for conservation.

"Raw data (wattage consumed) suggestions about how to consume less energy?" (P31)

"I'm not sure that it is possible, if it shows approximate money." (P22)

Their request does not indicate the dissatisfaction with the iconic representation. Instead, the insights from the qualitative analysis explained that the additional indexical information could 1) strengthen the correlation between the unconscious behavior and the changes of the coral reef imagery resulting in more awareness and 2) motivate change to a preferable state by showing the result of improved behavior more explicitly.

DISCUSSION: DESIGN REQUIREMENTS

Our analysis answered the two research questions: Ambient display can boost the awareness of their everyday and micro-habits so some users are motivated to change habits. Iconic representation through scientifically-related metaphors simulates emotions more than numerical data does. We articulate the design requirements along the stages of persuasion—from the awareness to behavior change, and the maintenance of the changed behavior. We also discuss the possible technical enhancement to our designs for the persuasive empowerment.

Early Stages: Raising Awareness of Unseen Issues

Revisiting the conditions of persuasive ambient display suggested earlier in this paper, we have come to a set of design requirements focusing on the early stages of persuasion. These principles are grounded in the aforementioned related work and the findings and reflections from our comparative study.

1. Minimal Domain focusing on micro-activity: In contrast to the visualization of collective usage of an entire residential building [17, 26], we focused on a micro-activity, a single appliance. The result of our experiment supported that one design condition of persuasive ambient display—*information from a focused domain*—is effective for people to become aware of the otherwise ungraspable habits. When they checked the immediate result of a small range of activity, they found the reasons easily enough to start an action without preparation. Other research that stressed immediate feedback [19] and learning of focused domain [37] also supports this design requirement.

2. Non-distracting feedback: Our design intention was giving minimal distraction to follow one design condition—*low distraction for checking*. Mac widgets are designed to be ignored by default and displayed only by bringing the Dashboard to the foreground. While seeing the Dashboard, the users did not feel distracted no matter whether they checked the tested widgets intentionally or simply glanced at them.

3. Subtle indicator for ambient tracking: Moreover, we may consider designing a more non-distracting system such as background image and upper menu bar on the desktop that users do not even have to take a specific action to see the feedback. As long as the system does not interfere with primary tasks, a subtle visual notification via color or shape change would be possible.

4. Visual fun: We designed Coralog by applying the two conditions of *representation through iconic images* and *visual appeal*. In terms of functionality, iconic images helped people understand the relationship between their actions and subsequent changes of real creatures that are sensitive to the pollution. In addition, designers may consider adding animations for more visual fun at a visceral level [28], as some Coralog users also wanted more elaborate transition of the coral reefs according to their health condition.

5. Accurate data from real users: While designing data-based system for persuasion, researchers should ask these questions: is the data personal or from a larger collective? Does the system merely represent external information or a user's activity? To make users aware of the problems caused by users' own activities, systems should present them with data about their own activities rather than general collective information about others.

6. Non-intrusive sensing: Researchers have been interested in how non-intrusively a system delivers information to users, but not how naturally it obtains the information from users. Even though some design prototyping for behavior change required *self-reporting* for data gathering [13], we argue that users should be exposed to the same environment while experiencing the persuasive medium, especially when they are not prepared to make changes or even aware of what needs to be changed.

Later Stages: Behavior Change and Maintenance

Each participant had a different user experience in many aspects such as usage frequency, perceived attractive points of the widgets, concentration, emotional attachment, and functional utility. These differences and his or her pre-set motivational level determine the depth of engagement with the systems. How intensely a user is engaged is connected to how they react to the feedback from the systems and to the level of persuasion. We discuss several aspects of persuasive media that encourage stronger engagement that may lead to further stages—*preparation, action*, and *maintenance* [6].

7. Rewards through iconic representation: We indicated that people responded more emotionally when they had faced the recovery of the coral reefs than the damage of them. The feedback for rewarding and encouragement should be visually pleasing, but not too abstract for a correlation between the action and effects and encouraging more when people behave well than poorly.

8. Personalized feedback: Some users did not show a considerable behavior change depicted as the decrease of idle time. We suspect that these users did not show a clear behavior change during the two weeks because the system did not provide them with personalized guidance beyond the simple and repeated feedback. A further advice system reflecting personal factors such as the level of self-motivation might lead them to more immediate action. Not only a timely suggestive feedback, but also a reminder of previously recorded habits would be useful for correcting negative behaviors.

9. Self-monitoring for maintenance: Participants who considered themselves already knowledgeable about environmental issues still thought Coralog was intriguing enough to help with their self-monitoring. Coralog helped them make sure to use sleep mode when they had to be away from the computer. This behavior reflects that ambient media could be useful for the latest stage of persuasion, which is *maintenance* through self-monitoring.

10. Leveraging network or social media: Previous research discussed the role of the social world intersecting personal lives in designing for sustainability [12, 26, 37]. Our participants also mentioned several ideas about networking among personal computers or family members for enhancement of the system. As long as social barriers do not obstacle, combining social media and ambient display would benefit for goal-oriented tasks in a larger context of community. In addition, reciprocal interaction encouraging others may help at the later stages of persuasion that functions external motivations.

Enhancement Opportunities of Our Design

Although the logging software detects "the data from real users" and the widgets represent the data, it needs to be improved. Since idle time in our systems is determined as no happening of mouse or keyboard input more than five minutes, it does not distinguish from the net "not in use" time. When participants found that their background operations such as running simulation for a long span and playing music or movie was not accurately reflected, they tended to lose motivation while oppressed against their primary tasks. As Chetty et al. suggested [2], if there existed a context-aware sensor that could detect the true usage regardless of the active usage of input devices, the ambient system would be more compelling as a user does not become doubtful or frustrated.

Some participants desired to see the real electricity usage. In fact, we attempted to show the actual electricity usage on Timelog, based on the request obtained from the preliminary user study. However, the electricity consumption is varied according to the various contextual factors such as model of computer, power plug/battery, and sleep mode/turning off. If a more elaborate technology that could distinguish such context were embedded, the information and the following effects on awareness would be more powerful.

Since our study originally focused on the early stages of persuasion that need increase of awareness, the duration of several weeks was reasonable as other studies [13, 19]. However, we observed users' attempt of actual behavior change and maintenance, a longitudinal field research of around three months would benefit to track these later stages of persuasion [4].

CONCLUSION

Changing individuals' lifelong habits to an ideal state in a short time is difficult. Addressing the motivational stages of behavior change, our critical study with fifty-two participants supported that ambient display is suitable for persuasion without obtrusive feedback. It helps to increase awareness of their problematic micro-activities. Additionally, it encourages behavior modification and helps maintain good habits of self-conscious people. Also, we found that iconic and metaphorical images triggered more awareness and motivation for future behavior changes through emotional attachment while indexical representation was beneficial to informative and retrospective purposes. Our research contributes to the intersection of persuasive design and ambient display in HCI research. Further, our study lay out a series of design requirements founded on the theories of persuasion and the findings from our comparative study. We expect future persuasive ambient media that incorporates our design requirements, such as context-aware and personalized feedback, would yield more behavioral changes and maintenance, which could be evaluated through a longitudinal field study.

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