Everyday Ambient Displays and the Potential of Peripheral Interaction

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Peripheral interaction and ambient displays are designed to occur outside the primary focus of attention. Very few papers have investigated the connection between peripheral interaction changing the output on ambient displays. To lay the groundwork for this pursuit, I review existing papers related to human interaction causing changes to ambient displays. This paper specifically explores peripheral interaction and ambient displays and how they can influence behavior, incorporate everyday objects, and occur in everyday environments. After a literature review of 11 papers, I conclude peripheral interaction and ambient displays should incorporate DIY user adaptability, integrate the human body, use text as well as abstract images to communicate information, relay literal and metaphorical information based on context, and be delivered consciously or subconsciously.

CCS CONCEPTS • Human-centered computing • Human-computer interaction • Interactive systems and tools

Additional Keywords and Phrases: peripheral interaction, ambient displays, ubiquitous computing

1 INTRODUCTION

Dourish wrote of a trend in computing that "allows computation to be made ever more widely accessible to people without requiring extensive training, and to be more easily integrated into our daily lives by reducing the complexity of those interactions" [5]. We have more control over our interactions with computers than previous generations without having to be skilled in coding or system functionalities. Along with the ease of interaction, computers have also become more widely available. A 2018 US Census report found that 92 percent of American households have a computer which could consist of a desktop, laptop, tablet, smartphone, or single board computer [10]. A study by the Pew Research Center found that in 2015, 66 percent of Americans owned at least two of the following digital devices: smartphone, desktop, or laptop [2]. The same study found that 36 percent of Americans owned all three digital devices [2]. This means two thirds of Americans have extra digital devices with screens in the home that could be used to display information peripherally and ambiently.

Raudanjoki et al. define ambient information displays as displays that deliver information through the periphery of human attention [14]. This paper will review some ambient displays that communicate abstract information through manipulating shadows cast in the house by plants, moving art installations in the entryway of an office building, and changing the color of lights in classrooms and hospital rooms [4, 15, 1, 3]. Matthies et al. write that "in peripheral interaction, short attention shifts from the main task to a secondary task occur, to either perceive feedback or provide input" [12]. This paper will review peripheral interaction methods that include Fidget Widgets, tangible tokens, and other secondary task activities [8, 6]. The aim of this paper is to build an understanding of how peripheral interaction methods can be used through everyday objects to display information on digital screens in everyday environments. If Americans can easily work with computers and have multiple screens around their homes, what kind of content can these computers show us peripherally that might help change lives for the better?

2 BACKGROUND AND MOTIVATION

Ambient and peripheral displays and interaction are closely related. They usually take place in the background of our everyday activities, not taking our full focus of attention from whatever tasks we are performing. Because we do the same things in the same environments almost every day, ambient and peripheral displays and interaction offer the potential to engage with different types of information that may be processed on different levels of consciousness. Daily engagement with a curated set of information that operates on different levels of consciousness and takes little extra effort to interact with could offer easy ways to influence our own behavior and moods that are cheaper and more effective than therapy. To investigate potential design for these spaces, we must first survey the developments of ambient and peripheral interaction and displays in the HCI field to develop a more informed understanding of its current state.

Shelton and Nesbitt provide a survey of developments of Ambient Information Systems from 1996 to 2016 [16]. The first Ambient Information system was the “Dangling String” in 1996 [14]. It was an eight-foot piece of plastic spaghetti hung from the ceiling to illustrate network traffic through movement and sound. The authors found that there is no universal definition of Ambient Information Systems. Because there is no universal definition, the authors discuss different aspects of ambient displays, media, information sources and the taxonomies developed to categorize them to create a better understanding of design in the field. One main distinction that Shelton and Nesbitt make is the difference between the levels of ambience in the displays. The purest form of Ambient Information Systems requires no interaction from the user and only delivers information. Because the pure Ambient Information Systems require no interaction, they can be classified as Calm Computing, where there is no requirement of input or extra effort from the user [16]. Semi-ambient displays require some form of interaction from the user to function and become relevant [16]. This paper will focus on semi-ambient displays that require some interaction with the user, making the user at least slightly more aware of the interaction and information.

Previous taxonomies are also investigated by Shelton and Nesbitt that distinguish design dimensions for Ambient Information Systems [16]. Ames and Dey created a design taxonomy for Ambient Information Systems that included the 11 following dimensions: intrusiveness, notification, persistence, temporal context, overview to detail, modality, level of abstraction, interactivity, location, and content. Shelton and Nesbitt identify that although Ames and Dey include intrusiveness and overview to detail, they do not focus on the key aspect of the periphery of attention [16]. Another taxonomy identified that does focus on models of attention was the Peripheral Display Toolkit [16]. The Peripheral Display Toolkit puts attention into the following four categories: preattention, inattention, divided attention, and focused attention [11]. In the preattention phase stimuli go unnoticed and do not influence the viewer’s perception [16]. During the inattention phase, peripheral stimuli may affect behavior through subconscious processing. During the divided attention and focused attention stages, peripheral stimuli are processed consciously through multi-tasking or singular focus. This paper is interested in investigating design for subconscious processing of information to influence behavior through the inattention stage and the multitasking conscious processing of both the divided and focused attention stages.

In their survey, Shelton and Nesbitt state the most well-known classification taxonomy for Ambient Information Systems was created by Pousman and Stasko [14, 13]. Their system puts Ambient Information Systems into the following four design dimensions: Information Capacity, Notification Level, Representational Fidelity, and Aesthetic Emphasis. This taxonomy is the most well-known because it allows each of the elements to be ranked from low, somewhat low, medium, somewhat high, and high, creating a more detailed reference to compare systems. The Information Capacity dimension represents the amount of different information sources that can be represented. The Notification Level dimension consists of the previous five categories of levels to alert the user. The Representational Fidelity dimension consists of the same five categories that represent how the data is displayed: symbolic abstract (low), symbolic letters and numbers (somewhat low), iconic metaphors (medium), iconic drawings (somewhat high), and indexical (high). The Aesthetic Emphasis dimension consists of whether the display is more aesthetic than functional and is also divided into the same five low to high categories as above. This paper is interested in design for low and somewhat low Aesthetic Emphasis dimension as it allows more functionality and has the potential to be more easily incorporated into everyday environments.

In their survey, Shelton and Nesbitt also identify that Pousman and Stasko coined four design patterns to apply to Ambient Information Systems that included Sculptural Symbolic Displays, Multiple Information Consolidators, Information Monitor Displays, and High Throughput Textual Displays [16, 13]. Symbolic Sculptural Displays show a single piece of information through sculpture. Multiple Information Consolidators make multiple sources of data available to the user and are usually screen-based. Information Monitor Displays are incorporated into the desktop computer of the user and are not novel in their appearance. High Throughput Textual Displays use icons and graphics to show multiple pieces of information to the user. Shelton and Nesbitt note that typical Ambient Information Systems focus on aesthetics, but High Throughput Textual Displays have little focus on aesthetics making them an atypical ambient system. This paper is interested in High Throughput Displays and similar ambient and peripheral systems that focus less on aesthetics and use everyday objects for the display of and interaction with information.

Now that a foundation has been established in the development and classification of ambient and peripheral displays and interactions, the proper steps can be taken to investigate the possibilities for daily engagement with information in this way and what may be the effects. All papers included in this review require some interaction with the user, making the user at least slightly more aware of the interaction and information, so this will not be a separate category I investigate. Four papers will be included in the category for the design of subconscious processing of information to influence behavior through inattention and the multitasking conscious processing of the divided and focused attention stages. Three papers will be included in the category for ambient and peripheral systems that focus less on aesthetics and use everyday objects for the display of and interaction with information. Finally, four papers will be examined in the category for lower Aesthetic Emphasis dimensions that allow more functionality and have the potential to be more easily incorporated into everyday environments.

3 METHODS

I reviewed 11 papers. All 11 papers were found searching the ACM Digital Library for the terms “ambient interfaces”, “peripheral interaction”, “ambient and peripheral interaction”, and “peripheral subconscious interaction”. I chose these papers because they all involved elements of interactivity, so the information was not just randomly playing in the background hoping to be noticed but required input from the user. These papers all involved ambient displays and peripheral interaction taking place in everyday environments like the home, the workplace, cars, and cafes. As I was looking for possible everyday applications of ambient and peripheral displays and interaction, the everyday aspects were more important than papers relying on heavily aesthetic artistic installations for ambient effects. As described above, the 11 papers are categorized into three subsections: Behavior Influence, Everyday Objects, and Everyday Environments. After the review of the papers, I will synthesize the ideas in a discussion section arguing for the potential to influence behavior on multiple levels of consciousness using ambient displays and peripheral interaction in our everyday environments with everyday objects. I will conclude with a section on implications for future work in this area.

4 LITERATURE REVIEW

4.1 Behavior Influence

This subsection will explore design for subconscious processing of information to influence behavior through multitasking, conscious processing, and inattention. Matthies et al. introduces the idea of Reflexive Interaction, an extension of the idea of Peripheral Interaction [12]. Reflexive Interaction is when a short secondary task is executed using interactions shorter than microinteractions without straining the user's attention. The authors classify HCI into three general classes: focused interaction, peripheral interaction, and implicit interaction [12]. Reflexive interaction is a subcategory of peripheral interaction. A reflexive interaction is enabled because humans can complete tasks with divided attention. Reflexive interactions may occur subconsciously and do not allow interruptions to the user's primary task. Matthies et al. give the example of a person riding a bike and getting a call [12]. The system would analyze the context and choose the body part that is not yet occupied with another task to alert to the phone call. The alert would be just noticeable and would not interrupt the current sequence of actions. Matthies et al. recognize a limitation of reflexive interaction is that it may only be enabled with feedback and input no greater than 2 bits [12]. Another limitation the authors found was extensive training is needed until the task is conditioned enough to enable performance of more complex tasks, like turning on a car's blinker while driving [12]. Matthies et al. recommend greater research on the optimal number of assigned input gestures that can be internalized while still enabling reflexive interaction [12].

What Matthies et al. miss in their exploration of reflexive interaction is the ability to take advantage of everyday tasks like cutting on a car's blinker to allow for opportunities like notifications and alerts. For example, if you were attempting to change lanes and the blinker lever became harder to move, the driver would become alerted that something out of the ordinary was going on. This type of alert might relate to information related to the direction they are driving in, such as not exiting the highway at the next exit. Or, to truly influence behavior on a larger scale, the driver could pre-program what that reflexive interaction means for that day, week, month, or life of the vehicle. This would be a way to communicate small alerts about desired behavior and allow the possibility for change to keep the interaction novel and reflexive.

Another way to influence behavior using ambient information and not straining the user's attention is through light indicators and beepless pedals. Cabral Guerra et al. proposes a new form of interaction between nurses and clinical alarm systems that interact through the periphery of attention [3]. In many intensive care units nurses are overexposed to alarms. Alarms can also affect patients, especially if they are already in a fragile state. Cabral Guerra et al. use a pictorial to present a study of peripheral interaction being introduced in a neonatal intensive care unit to reduce the occurrence and duration of audio alarms [3]. The study was conducted in the NICU of Maxima Medical Center. Peripheral interactions fit in this situation because they can enhance the use of the interfaces as secondary tasks while users are engaged in their primary tasks. Cabral Guerra et al. first conducted an ethnographic study using semi-structured interviews with nurses, biomedical engineers, doctors, and clinical psychiatrists at the site to identify where peripheral interactions could best be applied [3]. Then the authors did a focus group with seven nurses to validate their concerns with the system currently in place. Then the authors deployed a prototype in an anonymous hospital for a week [3].

Cabral Guerra et al. found that some alarms in the NICU like "low battery" and "out of water" could be prevented if the nurse was informed remotely in a timely manner [3]. A water supply indicator was developed that gradually changes color as the water level decreases. When the water supply is close to being out the light will begin blinking. If it becomes critical, the light will blink and an alarm will sound. Cabral Guerra et al. also developed a beepless pedal because their study found 25% of critical alarms happened while the nurse was in the room because of a movement the nurse made that disconnected wires or a machine [3]. The pedal could be used to quickly silence the alarm process without interrupting the nurse's primary task. Cabral Guerra et al. suggest more HCI research regarding nurses' routines is needed to develop ambient alert systems [3]. Also, further studies should be done to increase the sample size and the timeframe of the usability tests.

A shortcoming of the Cabral Guerra et al. study is that they didn't do a long enough study to find out how the nurses' behavior would change after learning the slow alert system of the light indicators for water and battery levels. If different indicators could be developed for different systems, maybe nurses' learning the general length of the indicators gradual changes might be incorporated into a change in work behavior that knows on a subconscious level to check the water after x number of weeks. Another shortcoming of the Cabral Guerra et al. study is that the patients could also take part in noticing the gradual change in the ambient lighting as they are easier to read than most medical interface screens. This would allow patients to play a bigger role in their own care and help nurses execute their jobs better by giving the patients easy information to influence nurse behavior and attention. Patients could also use this information in a negative way if they feel that the nurse is neglecting or ignoring their water level which could lead to bad feedback.

Outside of hospitals, ambient information systems have also been tested in schools. An et al. studied secondary school teachers and ambient lights in classrooms [1]. The authors wanted to test the lights while teachers were teaching to show teachers how and where they spent their time and attention across students in their classroom during the lesson [1]. An et al. were specifically interested in how to facilitate teacher's reflection in action, a significant skill for teachers to develop that helps optimize teaching behaviors in the moment, through using an ambient information system. The data came from a field study of 11 teachers across 22 class periods. The ambient information system was called ClassBeacons and consisted of small lamps on the desk of each student group or pair. The lamps would change colors from yellow to green to show teachers information about who they have been spending their attention on. If the teacher has been around a student a lot, then that student's lamp would turn green. To track the teacher's position a decimeter-level in-door tracking kit was used.

An et al. found ClassBeacons helped transform teachers' proximity and helped promote learner-centered pedagogy. Teachers liked that they did not have to read anything while teaching but could instead glance at the lights and see where they needed to be. An et al. suggest further studies should not rely on teacher recall to study reflective behavior but should combine measures such as eye-tracking and cognitive load assessment [1]. An et al. note a limitation of the study was the size of the proximity tracker the teacher had to wear, which should be made smaller and less obstructive in future studies [1]. Another suggestion teachers made for future studies is to be able to see attention distribution of students across multiple lessons, instead of just one class period.

A shortcoming of the An et al. study is that students may be made anxious by knowing what the light represents on their desk. Some students may call the teacher over early to change the color of their beacon so they don't have to worry about a random visit later in the class. This would change normal classroom behavior for both the teacher and the student because it creates the possibility of unnatural interactions caused by students who are trying to gamify the beacons for their own benefit. This same shortcoming could apply to the teachers' desire to see the distribution of attention of students across multiple lessons. Students could manipulate the attention of the teacher during one project so they are left alone for the rest of the semester. The manipulation of the beacons could be avoided if the change in colors were applied to something only the teacher sees, like the digital attendance roster. A frame around the student's picture on the attendance roster could change colors to let the teacher change their behavior without letting the student in on it too.

The three studies above in this section included participants that were aware of the intent of the ambient and peripheral interactions [12, 3, 1]. Rogers et al. conducted a study that kept the participants in an office building uninformed of the meaning of the ambient displays and why they were changing [15]. Rogers et al. conducted an in the wild study over eight weeks deploying three installations in an office building [15]. The three installations were Follow the Lights, The Clouds, and a data display called The History. These installations were placed near the elevator, in the public atrium, and on a wall near the entrance respectively. The authors wanted to observe the effect of people's perception of their own behavior in response to the installations compared to how they were observed behaving. To get this data, Rogers et al. focused on the daily decision workers and visitors in the building make about taking the elevator or the stairs [15]. Rogers et al. first surveyed 30 random people coming out of elevators about why they took the elevators. Survey participants informed the authors it was because they were lazy, carrying things, and it was easier than using other methods [15].

The first installation, Follow the Lights, was an abstract representation on the floor meant to distract people from focusing on the nearby elevator and guide them towards the stairs. The second installation, The Clouds, was an ambient display hung from the ceiling to be highly visible. The Clouds represented the number of people who took the stairs and the elevator as two clouds, one gray and one orange, that moved up and down. The Clouds would move every half hour in reaction to updated numbers of the people who took the elevator and the stairs. The third installation, The History, was a literal data visualization of the same elevator vs. stairs numbers represented in The Clouds installation that also used the same colors in pie charts. To collect data, Rogers et al. used sensor pressure mats near the stairs and elevator [15]. The authors also used observations and interviews along with an online survey sent four weeks after the study to everyone that worked in the building.

Rogers et al. found that people’s reactions to the installations changed over time and were different if they experienced the installations alone or as part of a group [15]. Most participants understood that Follow the Lights was meant to lead them to the stairs. Many participants did not understand The Clouds installation, only identifying that it changed but not knowing what behavior in the building changed it. Very few participants ever stopped to look at The History installation even though those that did claimed it was more informative than The Clouds. Most participants claimed their behavior had not been influenced by any of the installations. But, Rogers et al. found from the logged data that stair usage did show a statistically significant increase over the duration of the study [15]. Rogers et al. believe this suggests ambient displays can have an effect below the conscious level but are unsure if larger habits and behaviors can be changed by using similar displays.

One of the shortcomings of the Rogers et al. study is that workers in the building were not asked what type of behavior they would like to change. If the topic was something that connected to more workers, then the behavioral change could have been even more effective. The workers could have wanted to recycle more, or cut the lights off in their offices more, which could have enhanced their desire to change their own behavior on a conscious and subconscious level. Another shortcoming of the Rogers et al. study is that people rely heavily on routines for most of their work and home lives, and interfering with the workplace may be something that the workers were not appreciative of, which is possibly why they mentioned that they did not think their behavior changed at all.

All four papers in this section offer insights about ambient displays and peripheral interaction for behavioral change. Reflexive interaction shows that humans can complete tasks with divided attention, so alerts can be received which can result in a modification of their current behavior to adapt to a new behavior, like receiving a phone call [15]. Light indicators in hospital rooms can change the behavior of nurses by gradually alerting them to the existence of non-critical care issues which can be taken care of when they have the time [3]. Classbeacons also use lighting as a cue to reorient the teacher to the students who missed direct one-on-one time with the teacher during the lesson so everyone can get a more equal education [1]. Ambient installations in the workplace can influence the daily behavior of workers even if the workers don’t recognize their own behavior is changing [15].

The gap that needs to be addressed around behavior change through ambient interfaces and peripheral interaction is applying these designs to the home and individuals. In all the papers in this section, the workplace or outside of the home were the focus of the interaction. This brings up new sets of problems as we saw with patient and student exposure to the light beacons. Patients and students who understand what the light beacons indicate could manipulate their interaction with others sharing the space in positive or negative ways. In the home, individuals would have more privacy with the types of interactions and displays they set up. Displays in the home could be used to communicate other information, like how much of a book or article still needs to be completed. If these beacons were in busy areas of the home, they could act as motivators to complete tasks. Especially if living alone, people could experiment with different types of behavior change and not have to worry about others participating in their process. Future studies should look at ambient and peripheral displays using light and reflexive interaction within the home for individuals, couples, and families.

4.2 Everyday Objects

This subsection will examine ambient and peripheral systems that focus less on aesthetics and use everyday objects for the display of and interaction with information. Edge and Blackwell studied the use of the imprecise movements of digitally-augmented physical tokens in the periphery of workspaces [6]. The authors describe the design of and responses to tangible peripheral interaction. Edge and Blackwell note that peripheral technology is related to calm technology in that the users pull information from their environment when necessary instead of having information pushed on them [6]. Edge and Blackwell identify a gap in the field that has focused on the switch between the center and periphery of attention as states in the world rather than dynamic states of the mind [6]. The authors believed tangible objects placed around the periphery of desks while people worked would give them the opportunity to switch tasks between the center and periphery of attention.

Edge and Blackwell developed a tangible user interface that used tokens on an interactive surface whose movements were tracked by a camera mounted above [6]. The surface projects a halo around each token which displays information about their attributes. Edge and Blackwell discuss the construction of their interface using the analytic design process. The authors performed semi-structured interviews with staff and discovered that workers needed technology to help encourage conversations in the office and aid in organizing auxiliary work [6]. Edge and Blackwell also conducted a video study of desk work and found workers' hands were unused 25% of the time and were often used in eyes-free fashion when interacting with other objects on the desk [6]. The authors then developed five requirements for supporting auxiliary work: low bulkiness, high permanence, low shakiness, low rootedness, and low rigidity [6]. Edge and Blackwell's final design supported the peripheral interaction styles of glancing at the surface of the display occasionally, nudging the tokens to select them, and turning knobs to select a token's attributes [6].

Edge and Blackwell evaluated their system using three workers at a technology company for five weeks [6]. Participants reported that four-five tokens on the surface at once was all that could be handled without the surface feeling too cluttered. The authors found participants found the controls simple to learn, easy to remember, and supported fluidly switching back and forth between primary and peripheral tasks [6]. Participants also noted they liked being able to annotate the tokens by writing on them or placing other objects on them to help them be more quickly identified and remembered. Edge and Blackwell found the tokens also encouraged conversations between employees working on the same tasks who would transfer the token around the office as the task was handed off at different stages [6].

Edge and Blackwell's study was limited by the small number of participants involved. Interaction with the authors' tangible user interface could have been too specific to the needs of that workplace, so the results may not be generalizable in other types of non-technology offices. In terms of this paper's pursuit, this study was limited in its use of a desk for the interaction area. Even though many people spend their workdays at desks, there could be more novel information to be interacted with than work-related content. Another limitation is that Edge and Blackwell create new forms of tangible interaction that the user must learn, instead of incorporating some of the movements that users naturally make at their desks every day.

One study that does investigate natural movements that could be used as peripheral interaction opportunities was done by Karlesky and Isbister. The authors researched self-regulation using Fidget Widgets that people fiddle with in their hands while at their desks at work or at home [8]. The authors conducted a qualitative study that collected 132 examples of fidget behaviors and objects. Karlesky and Isbister used grounded theory to reveal patterns of fidgeting behaviors and objects using the website Tumblr [8]. The authors wanted to collect diverse data, so they had internet users submit images, videos, and text descriptions of what they fidgeted with while working on their computers. The Wall Street Journal ran an article about the study that boosted the submission of fidget objects to the authors' website until the total reached 91 individuals submitting 132 object descriptions, 83 images, and 20 videos [8].

Karlesky and Isbister found that everyday objects were commonly used such as paperclips, pens, and balls. But the authors also found that irregular objects were also being used to fidget with, such as door lock mechanisms and tape [8]. Participants in the study claimed to use the fidget objects in repetitive patterns, creating the same sensation repeatedly. Some participants used self-regulation to modulate their inner states through fiddling with an object. Karlesky and Isbister recommend designers work to create mindless short activities that help fidgeters regulate their behavior while on their computer [8]. The authors believe there is a complementary interaction design space for objects around computers to help focus, creativity, attention, and energy [8]. Karlesky and Isbister acknowledge that peripheral interaction is an area to develop as it relates to self-regulation alongside digital work practice.

One shortcoming of the Karlesky and Isbister study is that all the fidget objects being used were not connected to a computer or digital display. In the peripheral interaction this paper is interested in, fidget objects would need to have some form of digital interactivity that could be displayed on the screen or in the environment to pair the self-regulating behavior with specific information the user desires. Another shortcoming of the study is that all the participants were aware of their fidgeting behaviors to want to contribute to the study. Many more people could fidget with objects at their desks subconsciously, leading to a large amount of behavioral data being lost. Future studies should involve users in laboratories under observation and in the wild observation of people at their desks during work.

Hausen et al. introduced an experimental method for the evaluation of peripheral interaction in early design phases [7]. Digital devices require us to use an all or nothing approach instead of allowing interactions like singing while we cook, talking while we walk, and drinking while we read. Hausen et al. conducted a case study based on in-situ deployment. Researchers presented an event-based task in parallel to an artificial peripheral task. Participants had to input a number on a keypad corresponding to the specific combination of shape and color. The participants were then invited to a group discussion. Participants were stressed or bored with the activity, so a continuous primary task was then developed and tested where participants had to click to remove shapes of a certain color displayed on a sidebar window. When all items were removed, a new round would start immediately. Then Hausen et al. conducted a case study comparing the field and the lab [7]. The case study involved participants controlling an audio player by carrying out simple commands while keeping focus on a primary task. The peripheral controls were graspable, touch, freehand, and media keys.

Hausen et al. observed more errors in the primary task and the peripheral task with experienced users, but this was thought to be because they were involved with the in-situ testing they developed sloppier interaction methods. In the lab tests, Hausen et al. found more usability issues. The authors had a technical limitation in the tracking of freehand gestures and misinterpretation of short gestures for the study. Hausen et al. feel their study enriched the number of evaluation methods available to designers of peripheral interaction. The authors concluded that preliminary lab experiments will enable more successful field deployments of peripheral interaction interfaces [7].

A shortcoming of the Hausen et al. study is that the peripheral tasks were not that meaningful. Picking out shapes while more focused on another task is not how most people would multitask while working at a computer. The control of an audio player through simple gestures is also not a realistic peripheral interaction activity as there are already many built-in shortcuts to do this on computers and smart watches. The type of multitasking engagement Hausen et al. envisions still deals with everyday objects and activities because it involves working at a computer and controlling an audio player, but it does not introduce novel interaction methods to achieve the same results. Hausen et al. show how we can engage with multiple interfaces at once that focus less on aesthetics and use everyday objects and activities.

Overall, the papers in this section show that people multitask when performing everyday activities with everyday objects. Edge and Blackwell showed people are engaging with multiple objects on their desks while they work without looking at the objects [6]. Karlesky and Isbister showed many people complete their work at a desk while fiddling with objects in their hands for self-regulation and other purposes [8]. These systems focused less on aesthetics and used more tangible and screen-based methods of common interactions to multitask. A gap in the research in this area is that the multitasking peripheral interactions are not meaningful as in the Edge and Blackwell and Karlesky and Isbister studies or realistic as in the Hausen et al. study [8, 7]. For Edge and Blackwell, the meaning of the tangible tokens was work related, but may not be personally meaningful to the users of the interface [6]. Creating peripheral interaction with content that was personally meaningful may help the interface become more integrated in daily use. For Karlesky and Isbister, users submitted their own objects and unique tangible interaction methods what held meaning as the users worked throughout the day [8]. Future studies should be done to turn fidgeting into peripheral interaction by embedding fidgeting objects with sensors that can change the display of meaningful information somewhere in the user's environment. For Hausen et al., to make the multitasking interactions meaningful the peripheral tasks should not be simple shape clicking or music controls, but instead the shaping of content displayed elsewhere that is more complex than on/off [7]. If future studies focus on meaningful and natural multitasking where peripheral interaction is controlling some element of an ambient secondary display in the environment of the user, then they will be getting closer to the type of system this paper is interested in.

4.3 Everyday Environments

This subsection will investigate ambient displays and peripheral interaction design for low Aesthetic Emphasis dimensions that allow more functionality and have the potential to be easily incorporated into everyday environments. Colley et al. studied manipulating the natural shadows produced by houseplants to display ambient information [4]. The authors used back projection onto a screen that was made to look like a wall [4]. A lamp was added to make it look like the shadow was naturally cast. Colley et al. conducted an exploratory study with 6 participants in a focus group. Participants were asked to think aloud during the study and then participated in a discussion and filled out individual questionnaires. There were 6 static images and 2 animated images of the plant shadow. The static shadows were manipulated to show a bee, to have the leaves droop, to be blown by the wind, to be spikier looking, and others. The animated images changed the size of the plant and the sharpness of the plant's shadow.

Colley et al. found the bee on the plant shadow did not result in a common interpretation by the participants. Participants connected the drooping plant shadow to either the plant or the participant needing water. The animated images were said to be more visible by participants and related to concepts like an appointment coming closer and progress in some area of their lives. The participants were interested in the shadows but felt the psychological effect could be negative for pets, children, or the elderly. Participants were concerned that an unnatural shadow would distort their reality over the long term. Other participants said it could be useful to act as reminders for things, but they would want to know what they were being reminded of and not want to think hard to figure out what it was trying to communicate to them after working all day.

There were many limitations in the Colley et al. study. One limitation of the study was the participants were not able to link abstract meanings to the shadow visualizations, always linking the meaning to the plant that was displaying the shadow. Another limitation of Colley et al. is participants were not aware of how their behaviors were influencing the displays of the plants. Plant shadows, even though most people are familiar with in their homes, may be too abstract to display the type of information necessary to influence the subconscious or change behavior. If the shadows were able to incorporate more words and images, then studies could trace the subconscious influence on people's behaviors and moods. Another limitation of Colley et al. is that the shadows were thought to be related to long-term alerts like appointments instead of information that was relevant to participants in that moment. If the shadows could become more of a visual display that is projection mapped within the area of the shadow, the information being displayed might be made to feel more relevant to the user in that moment.

A similar study investigated the use of human shadows as ambient information displays. Raudanjoki et al. created artificial human shadows and conducted a study on users in a cafeteria setting [14]. Ambient information displays deliver information through the periphery of human attention. The human shadow display was created using projection rather than using AR. Raudanjoki et al. chose to use shadows as ambient information displays because humans are naturally aware of shadows. The authors identify that shadows have been used as themes in art for centuries [14]. Raudanjoki et al. performed an exploratory study on user perception and design requirements of using shadows. Researchers used a back projection with a short-throw projector in a cafeteria setting. The study used two participants at a time seated at a small table. The shadow of an actor was projected in 6 static and 2 animated shadows. The shadow would pick up a book, become surrounded by spikes, change into bubbles, take a coffee cup and drink from it, and sit still. Participants sat at a table near the shadow and were asked about what they saw and how they perceived it. The participants were encouraged to think out loud during the study and were given a questionnaire at the end. 12 participants in total took part.

Raudanjoki et al. found many participants did not take notice of the shadow when they first entered the setting [14]. The movements of the shadow were reported to be unnatural and asynchronous. The human shadow was also seen to be an instructor as participants would mimic what the shadow was doing. Generally positive feelings were reported by the participants. Unnaturally modified shadows provoked the strongest reactions, including laughter and surprise. The researchers felt they were limited by the location and the quality of the animations of the shadows.

One shortcoming for the Raudanjoki et al. study was that the participants did not know the reason or meaning behind the ambient display. Because participants were confused, the full effects of the ambient display could not be known in the study. Another limitation was the lack of ability for the shadows to be able to display text or other meaningful images to the participants. For instance, if the human shadow had held fingers up to show how much longer an order would take until it arrives at the table, the shadow could have been a more understandable and relevant to the context of the cafeteria environment. Another limitation of the shadow in the Raudanjoki et al. study was that it was reported to be unnatural, creating suspicion in the participants who immediately begin attempting to figure out what was going on instead of letting it ambiently affect them.

Kunze et al. investigated the process of triggering awareness ambiently when focus is needed [9]. The authors used the everyday environment of a car to develop a new system to alert drivers of automated cars when they need to take back control of the vehicle. Previous systems relied on instrument clusters in the dashboard to deliver this information which increased the workload of the driver and their possibility of missing signals. A peripheral awareness display can be a means of presenting information to car operators without requiring them to switch their gaze between several areas in the car [9]. Peripheral display is a term used for interfaces that are not within the user's primary focus of attention and that function as a tool for communicating information about a secondary activity of a user.

Kunze et al. designed an initial prototype with four levels of increasing uncertainty [9]. The levels of uncertainty were communicated to the user through vibration motors in the bolster, seat pan, and back rest. Changes in color of the display were used in addition to the vibration feedback. The study was conducted in a driving simulator. 24 participants took part with an average age of 27. Fog was used as an indicator of uncertainty in the automated car. The independent variable was display type. After each scenario the participants were asked to fill out a questionnaire. Then semi-structured interviews were conducted following the completion of both scenarios. Kunze et al. found that when using the peripheral awareness display safe driving performance improved [9].

One of the limitations was that the Kunze et al. study is it only dealt with the uncertainty of fog density. Another limitation was the sample size of the study. Kunze et al. did not see further applications to other activities such as peripheral awareness. One shortcoming of the Kunze et al. study regarding the pursuit of this paper is it did not involve the user in the interaction with information unrelated to the drive. It would be interesting to develop metaphorically related information tied to these same alerts such as fog and uncertainty in the car to areas that are foggy or uncertain in your life. If this was a daily experience, imagine the self-improvement and self-exploration people could engage in as they go about their routine drives to destinations.

A study that moves from the possibilities of self-exploration to social exploration was AmbiDots [17]. Thompson et al. explore the design and implementation of AmbiDots for use in casual social interactions. AmbiDots is meant to be a playful interactive system that helps mediate conversation and social interactions in everyday settings like bars, cafes, and restaurants. Thompson et al. note most early ambient systems focused on output with little to no interactivity [17]. Of interest in the AmbiDots design was to elicit emotions from users rather than productive ends. AmbiDots uses a visual language of ambiguously behaving colored dots in a dynamic interface that responds to motion and objects by being projected on a flat surface [17].

For feed, Thompson et al. held a formative workshop with a non-interactive prototype in a controlled laboratory environment where participants took part individually [17]. From the workshop the authors found that participants expected to interact with the system by using their hands, they expected dots to be attracted to objects and repelled by motion, and that the dots seemed to be pre-programmed rather than agent driven. Thompson et al. used Computer Vision to recognize objects and motions within the interaction space. The output of interactions were altered behaviors of the dots. Each dot had character defining variables: purple was excited and fast moving, yellow was curious and moderate moving, cyan was shy and slow moving, and green was normal and moderate moving [17]. Thompson et al. conducted an exploratory user study to reveal insights about the effect that ambiguous ambient systems have on users in casual social settings. 22 participants were involved in the pseudo-social study environment of a semi-public shared office building. The trials lasted 10-12 minutes. The data was collected through a questionnaire and an unstructured interview.

Thompson et al. found participants responded positively to the trial experience. Another key finding of the study was the participants found the interactions relaxing [17]. Participants also felt that AmbiDots were a conversational aid. Another common theme across the data was a sense of intrigue and interest from participants. Some participants thought the dots were not engaging. Overall, Thompson et al. found that AmbiDots did not hinder conversation and many participants claimed it improved their social experience. The limitations of the study were that this was a pseudo-social environment and should be attempted in a field study. Another shortcoming of this study is that the dots were just visual and did not directly represent any text or learnable content.

This subsection on everyday environments showed where we spend most of our time can be places to successfully have ambient displays and peripheral interactions. Shadows were successfully manipulated in to influence viewers in the Colley et al. and Raudanjoki et al. studies [4,14]. Alerts were successfully communicated to improve the awareness of automated car drivers in Kunze et al. study [9]. Social conversations were enhanced by animating dots on a table around drinks using computer vison in the Thompson et al. study [17]. The gap in this subsection of papers is that actual text-based information is not being communicated to users yet. The shadows, car alerts, and AmbiDots all communicate something to the user, but nothing out of the ordinary. People need to be able to gain more control over their everyday environments to communicate the types of information they want to see using these same channels of display and interaction.

5 DISCUSSION

From our literature review, we can identify five important areas to help guide future research in peripheral interaction and ambient information displays. The ability for users to perform DIY adaptations to their peripheral interactive elements can be gleaned from the Edge and Blackwell, Karlesky and Isbister, and Hausen et al. studies [6, 8, 7]. The need for better integrating the human body, especially regarding the public vs. private communication of ambient information, can be drawn from the An et al. and Cabral Guerra et al. studies [1, 3]. The possibility of communicating text ambiently instead of abstract representations can be culled from the Rogers et al., Colley et al., and Thompson et al. studies [15, 4, 17]. The opportunity for relaying context based literal or metaphorical information can be taken from the Raudanjoki et al and Kunze et al. studies [14, 9]. Finally, broadening the scope of peripheral and ambient interaction to both subconscious and conscious consumption can be launched on the findings in the Rogers et al. and Matthies et al. studies [15, 12].

5.1 DIY Adaptability for Users

Three of the papers reviewed show users should have the opportunity to adapt their ambient and peripheral interaction methods in their homes and work environments to better suit their unique needs. Edge and Blackwell noted that participants in their study began to annotate their tangible tokens to help differentiate between multiple tokens [6]. The authors also identified that participants adorned their tangible tokens with objects that allowed them to be handled more easily in their unique workflow [6]. In the Fidget Widget study, Karlesky and Isbister showed the variety of everyday and unique objects people fiddle with while working at their desks [8]. Both studies show when designing for peripheral interaction, users should be able to incorporate their own customizations to the interaction sensors or be able to incorporate objects they already use into the peripheral interaction system. This incorporation would allow users to adapt to peripheral interaction methods more naturally or use objects already familiar to their self-regulating behavior during work.

Taking DIY adaptability even further, Hausen et. al found when comparing experienced and novice users performing main and peripheral tasks, experienced users produced sloppier interactions with peripheral devices because they felt too experienced using them [7]. If users had the ability to adapt their peripheral interaction methods when they became too familiar, then users could maintain accurate interaction methods for peripheral tasks. This might include allowing users to change sensors on tangible objects or alter what peripheral gestures are being tracked by computers. DIY adaptability for users allows for variety in peripheral interaction methods, meeting the needs of each unique individual.

5.2 Integrating the Human Body

Two of the papers reviewed show the need for using the body to receive the communication of private information rather than displaying it ambiently. An et al. described the implementation of ClassBeacons, ambient lights on student desks that changed color depending on where the teacher had spent their time and attention [1]. But because students could also see the lights, they were aware of the same information the teacher was. This awareness creates opportunities for students to learn how to manipulate the system and the behavior of the teacher by timing their interactions with teachers so they can be left alone for the rest of the class. The problem of the public communication of information was also seen in the Cabral Guerra et al. study as light indicators were used that changed color to represent levels of non-critical systems like water [3]. The light indicators were also in full view of the patients, who could think that nurses were not providing the level of care necessary because they ignored the non-critical light related to water levels on multiple visits to the room. A way to communicate this information more privately to the nurses would be through using their bodies. If teachers and nurses were outfitted with interoceptive sensors on their bodies, they could be privately notified of alerts when they enter rooms or are near students or patient equipment that needs to be replaced.

5.3 Text Displays

Three of the papers reviewed show the potential for incorporating text instead of abstract imagery for the ambient display of information. Rogers et al. included The History installation as a literal representation of the data they were visualizing more abstractly in The Clouds and The Lights installations [15]. The History included pie charts with labels, a key, and the same colors represented in their ambient information installation The Clouds. Rogers et al. found that many people in the office building ignored The History because it was not as eye-catching as the other installation, but those who did pay attention found it easier to read, interpret, and talk about than the abstract representations of the same data [15]. This finding shows that incorporating ambient information that displays text alongside more abstract methods of display can be more beneficial to the viewer. Even further, the abstract ambient displays could occasionally include text explaining what they represent or what caused the changes in appearance.

Another paper that showed the potential for including text in ambient displays was by Colley et al. regarding the houseplant shadows [4]. Participants in the plant shadow study noted that they could not figure out what the shadows were supposed to represent and would not want to waste time when they were tired trying to decipher abstract ambient displays. Participants also thought the shadows would act as good reminders for upcoming events or appointments, but they would have to know what information was being presented. If text were incorporated into the projection of the shadows, users would have a better idea of what was being represented. Text wouldn't have to be continuously displayed, but could be flashed periodically, maybe every 15 minutes to maintain peripheral awareness but not distract from regular activities. The user could also choose what text they wanted to display and the timing of the display, so the ambient information could be more effectively consumed.

The third paper that showed potential for the incorporation of text in the display was AmbiDots [17]. Thompson et al. created a surface that displayed animated dots that circled around cups that were set on the surface as a conversational aid in a social setting [17]. Some participants were intrigued, but others were not engaged by the animations. A way to enhance the engagement and conversation of participants is if text was represented circling the cups alongside the AmbiDots. The text could be information about the person across from you at the table, such as a lists of likes and dislikes, a curated set of facts, or even CV information. Seeing interesting things about nearby people surrounding your drink may increase conversational engagement during these social events. The text display could also be carried into a home installation of the AmbiDots system, where information from family members they wanted communicated could be displayed, or notes from children's teachers, or local news and neighborhood alerts.

5.4 Linking Literal and Metaphorical Information to Context

Two of the papers reviewed show the opportunity for incorporating literal or metaphorical information in ambient displays related to context. In the human shadows study, Raudanjoki et al. found participants wanted the projections to represent information relevant to them in the cafeteria setting [14]. The information on the ambient display could be linked directly to the context of the setting and display information like how far along a food or drink order is from being at the table. Other types of ambient information that could be displayed in a cafeteria setting could be shadow projections of proper dining etiquette, showing which utensils work best with which foods, and showing waiter or waitress approved methods of calling them to your table, etc. The ambient display of literal information then would link directly to the context of the situation, helping users understand abstract projections better and contributing to a more positive cafeteria atmosphere.

A paper that presents an opportunity for metaphorical information represented ambiently and peripherally was the driving study [9]. Kunze et al. developed a system that used fog to indicate uncertainty to the driver. Even though the communication of literal information is critical during driving, it also presents the opportunity to be alerted to metaphorically related information about a driver's life. If the driver were to keep a daily journal of their thoughts, a computer could then analyze the writing and attach it to metaphorical representations of interactions in the car. Some examples would be cutting on the windshield wipers and being reminded of an event you need to see clearly, or cutting on the AC and being reminded of an experience you need to become less angry about, or opening the window to get fresh air and being reminded of a time you really enjoyed a hike. Linking metaphorically relevant information to necessary interactions in the car presents another design opportunity for the ambient display of information.

5.5 Subconscious vs. Conscious Peripheral Interaction

Two of the papers reviewed show the possibility for subconscious and conscious applications of peripheral interactions. The Rogers et al. study showed participants' behavior was affected by the three installations even though they were unaware of it [15]. In that study more participants took the stairs because of subconscious connections made between the lights on the floor, the moving clouds on the ceiling, and a data display off to the side [15]. Imagine the ethical ways ambient displays could alter behavior in public spaces, guiding people towards important landmarks or safe spaces. Ambient displays could be incorporated in schools to curb moods and enhance learning underneath students' awareness. There is also the negative side of subconscious ambient displays if employed in shopping experiences or other times to manipulate and limit the free choice of the public.

Another paper that showed the possibility of subconscious peripheral interactions was Matthies et al. on reflexive interaction [12]. The authors defined reflexive interaction as short microinteractions that don't interrupt the primary task [12]. These interactions allowed information to be relayed to the user at a level just below awareness as they were engaged in another task. Because the alerts came on an unused part of the body, awareness would not immediately be drawn to them, but would gradually grow into awareness as the user became less focused on their primary task. Types of bodily peripheral alerts like this would benefit the relaying of information other than phone calls. Reflexive interaction could allow information to be stored in different areas of the body, remembering an alert on your left calf means you need to buy toothpaste at the store, or an alert on your right elbow means you need to shake hands with someone before you leave the meeting. Users could program their own alerts and use them to help subconsciously nudge them toward their desired behaviors.

6 CONCLUSION

Technology is now at a place where unsophisticated computer users can easily alter their home or work environments [5]. Users can download free projection mapping software or buy cheap smart lightbulbs and program them to cue certain reminders. This option should be expanded from just reminders to the ability to reprogram your subconscious as you go about your daily activities. Text and information can be selectively curated to be displayed while you are eating, brushing your teeth, driving in your car, etc. This text could be displayed ambiently somewhere in your surroundings on a spare digital screen where you barely notice it, just like a shadow or the text around a drink on the table [4, 17]. Better yet, if this content were activated through peripheral interactions such as fidgeting, there might be the possibility to condition your psychology to tie the repetitive action to specific content, therefore changing your behavior and character in a way you desire [8].

Future work should investigate incorporating text and less abstract visual content into ambient displays and attempt to influence the subconscious of users over a long trial period. Future studies should be run to investigate how people might want to alter their environments to incorporate ambient information displays. Studies should also investigate what type of content users would want to see in their periphery daily. Some users may want affirmations, goal statements, or motivational words. Other users may want study guides for classes they are taking displayed peripherally in specific rooms of their house to explore spatial learning techniques. Each person's unique psychology may require a unique brand of content along with unique ambient displays and peripheral interaction techniques. I encourage readers to experiment with peripheral interaction methods to help uncover new ways of experiencing information.

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