Self-Adaptive Multimodal-Interruption Interfaces

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ABSTRACT

This work explores the use of ambient displays in the context of interruption. A multimodal interface was created to communicate with users by using two ambient channels for interruption: heat and light. These ambient displays acted as external interruption generators designed to get users' attention away from their current task; playing a game on a desktop computer. It was verified that the disruptiveness and effectiveness of interruptions varies with the interruption modality used to interrupt. The thermal modality produced a larger decrease in performance and disruptiveness on a task being interrupted than the visual modality. Our results set the initial point in providing the theory behind future self-adaptive multimodal-interruption interfaces that will employ users' individual physiological responses to each interruption modality and dynamically select the modality based on effectiveness and performance metrics.

Categories and Subject Descriptors

H.5.2 [**Information Interfaces And Presentation**]: User Interfaces– *Haptic I/O, Evaluation/Methodology, Interaction Styles*; H.1.2 [**Models And Principles**]: User/Machine Systems-*Human Factors.*

General Terms

Design, Experimentation, Human Factors.

Keywords

Adaptive Interfaces, Ambient Displays, Interruption, Modalities of Interruptions, Modalities of Interruption, Multimodal Interfaces, Multimodal-Interruption Interfaces, Output Modalities, Physiological Feedback, Thermal Displays.

1. INTRODUCTION

The use of interruptions is key in the design of human-computer interfaces. Most research about the effect of interruptions can be summarized in that a user performs slower on an interrupted task than on an uninterrupted task, that is, interruptions are perceived as disruptive. The research presented here goes a step further, discovering the effect of two different interruption modalities on performance and disruptiveness.

Advances in computer technologies have enabled the creation of systems that allow people to perform multiple activities at the same time. Interruptions are common in today's multitasking computing environments. Multitasking is useful and natural, however it also introduces the side effect of being interrupted constantly. Unfortunately, people have cognitive limitations that make them susceptible to errors when interrupted. Thus, researchers have investigated interruptions by looking at how and when to interrupt users in a multitasking environment [3,6]. In general, current computer environments are becoming more and more complex, with an increasing number of tasks and an increasing number of issues computer users have to keep track of [5].

Traditional human computer interfaces (HCI) found in desktop computers are not taking full advantage of the fact that humans have extraordinary sensing capabilities in use all the time. Despite the progress made in the past two decades in the area of haptic interfaces, these interfaces have not yet become widely used in human computer interfaces [14].

Past work provides evidence that there are substantial advantages in efficiency by using multimodal interfaces [9], the main focus of multimodal HCI research has been on combining input modalities – such as speech, pen, touch, hand gestures, eye gaze, and head and body movements– rather than using multimodal outputs to take advantage of human sensing capabilities.

Human senses differ in both, precision and speed. Vision and touch are more precise and faster than hearing for the perception of object properties (shape, texture, direction, distance and size). Hearing allows for a better perception of temporal events (duration, pace and rhythm) [16]. The common and unique characteristics of the human senses allow for the design of computer interfaces that use multiple output modalities and furthermore, computer interfaces that arbitrate between these modalities based on their disruptive effect.

In order to build these systems, there needs to be a foundation on which to base these decisions. This work sets the initial point in providing the theory behind future self-adaptive multimodal interfaces by looking at the effect of different modalities when used as interruptions.

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2. APPROACH

This work explores the use of ambient displays in the context of interruption. A multimodal interface was created to communicate with users by using two ambient channels for interruption: heat and light. Ambient displays present information in the modality and form that can be interpreted with a minimal cognitive effort [17]. They also act as external interruption generators designed to get users' attention away from their current task. Interruptions are presented in the form of heat and light. Ambient displays serve a purpose other than the mere presentation of information—they serve as a media for interruptions.

This paper presents an exploratory experiment, designed to test the effect of different modalities when used as interruptions. The purpose of these experiments is to identify the key factors that influence the perceived effect of each modality. One of the main hypotheses of this paper is that users' performance differs based on the interruption modality. A second hypothesis states that the perceived disruptiveness of an interruption varies depending on the interruption modality. Finally, an alternate hypothesis states that subjects' performance is negatively affected if interrupted by their non-preferred modality.

3. EXPERIMENTAL DESIGN

This experiment was designed to test the effect of different interruption modalities. The experiment attempts to answer questions about what parameters a computer interface could use to determine the proper interruption modality to use. Tactile and visual modalities are examined in this research. Tactile displays have recently been explored, but typically in the form of vibration [15]. Neurophysiological studies show that fingers and hands are one of the most sensitive areas of the body and have relatively large areas of representation in the cortex [10]. Thus, heat is used here as a novel ambient display to generate interruptions. Since fingers and hands are well represented in the somatosensory cortex, they provide with an excellent output channel for computer interfaces. A preliminary experiment showed that heat was a good interruption modality because of its novelty and its sense of immediacy [13]. The second ambient display utilized is light. The same preliminary experiment proved light was a good interruption modality because of the domination of the visual system over the other senses.

The interruption of people during human-computer interaction is a high-level interdisciplinary topic. Interruption is a complex process that involves many subtle low-level mechanisms of human cognition [1]. However, these individual mechanisms are not the focus of this experiment. It was decided that a simplistic and typical task like those used in studies of low-level topics of human cognition, would be inappropriate for this experiment. Therefore a reasonably complex experimental task is used to elicit the appropriate cognitive load. It is possible to investigate the process of interruption at the level of user interface design without fully understanding the many subtle low-level cognitive mechanisms involved [6]. In this experiment, the smaller effects are ignored and isolated from the high-level effects by looking only into aspects of the human-computer interaction.

An abstract task was chosen. It is a simplified model of common real world tasks. Examples of people performing this type of tasks are software developers. A debugging task, for example, requires a software engineer to identify and keep track of variable values as they change over the execution of the software. A software engineer has to create a mental grid and memorize several values while looking for the next line of code to execute. These identification and tracking tasks impose a high cognitive load and interruptions during this process causes errors, allowing for observations of subjects' responses to be easily broken down into discrete units. The experiment is set in the context of a computer-based adventure game, similar to online Multi user Dungeon (MUD) games, where the player has to issue commands to the computer in order to achieve certain goals. Gillie, et al used this approach [4]. A MUD (Multi-User Dungeon) is a network-accessible, multi-participant, user-extensible virtual reality and has an entirely textual interface. Participants type commands and the computer displays text corresponding to the action taken. Participants have the appearance of being situated in an artificially constructed place.

3.1 Method

Subjects were asked to perform a high level cognitive task involving a text-graphic hybrid of the MUD game described before. The task is a computer game that presents a challenge to subjects and keeps them engaged. The subject's task is to read directions, memorize a list of items presented to them, explore several locations around a small geographical area, create a mental map about the location and its contents, take objects in the specified order, and decide the next location to go to. This task provides several performance and disruptiveness indicators: score, speed, error rate and overall time. Czerwinski presented a similar experiment where subjects navigated a list of items searching for a book title. The investigator used a memory task to look for effect of disruption [3].

While subjects perform the primary task, an ambient device attracts their attention by changing temperature or by changing light intensity. They then have to acknowledge the interruption and perform a secondary task: read a list of words related to the same topic, similar to a free recall test. Interrupting messages are organized into networks of associated ideas, so that information that fits a schema and may be easier to remember. Every message contains several highly associated words using pre-established association strength norms to create lists of words categorized into four groups: rough, sleep, rain, and chair [12]. This dual-task of the experiment is conceptually simple, but difficult to perform due to the high cognitive load.

The program monitored subject's performance during the duration of the entire experiment by recording: commands issued, errors committed, reaction times, modality used, and other measures. These measures were grouped into three main categories: disruptiveness, performance, and effectiveness. Disruptiveness is defined as the error rate produced by the interruption modality in the primary task. Performance is defined as the time spent taking objects. Effectiveness is defined as the time taken by the user to acknowledge an interruption.

Measures of disruptiveness include the number of reminders before and after an interruption, the number of requests for inventory before and after an interruption, the number of errors taking the wrong object before and after an interruption, the number of errors going in the wrong direction before and after an interruption and the time taken to recover from an interruption. Measurements of performance include the time spent to take each object before and after an interruption, and the time spent deciding before selecting any option. The single measurement for effectiveness, related to how fast each of the modalities is noticed, is the time taken to acknowledge an interruption message. Other measures taken, for descriptive purposes, include a subjective evaluation to preferred modality and an open questionnaire about subject's experiences with the two modalities used.

3.2 Participants

23 subjects were randomly recruited and compensated for their time. The sample consisted of 14 males and 9 females with ages ranging from 22 to 34 years.

3.3 Material

A lamp, as an ambient display presents information according to its intensity. This experiment explores the transition in an ambient display from the background to the foreground. A light feedback controller adjusts the power going to a bed lamp located at the periphery of subject's field of view (approximately at a 45-degree right to the screen). The brightness level ranges from 5% to 95%.

Three peltier devices connected in series fixed into a copper mouse pad compose the heating device. This Thermo-mouse pad has the ability to warm a wide area in contact with the user's hand. Figure 1 shows a working prototype of this system. The temperature moves from ambient room to a warmer temperature at a rate of about 1 °C per second. (Ranging from 22°C to 40°C).

These two devices are controlled using a proportional feedback controller that also includes a generic RS-232 serial interface so that any program capable of handling serial communications can calibrate them, specify the desired settings or control them. Figure 2 shows a modular diagram for the feedback controller implementation.

Figure 1. Thermo-mouse pad implementation. It warms a wide area in contact with the user's hand.

This experiment utilizes a hybrid version of a MUD game. The application combines a text-based game and a graphical game. Figure 3 shows an implementation of the application interface. All information pertaining the game is presented using a text window and the user interacts with the game using a mouse. Using a mouse to interact with the computer rather than a text only interface is a requirement since the heat stimulus is in the thermo-mouse pad.

The application has five options available:

1) "Options" - presents a description of the user current location and objects available at that location.
2) "Remind Me," - reminds the user of the task at hand. Subjects were expected to press this button after coming from an interruption and whenever they need to be reminded of the list of items to take.
3) "Take" - takes the object present at the current location.
4) "Inventory" - displays a list of items that were already taken.
5) "Message" - displays a message when an interruption is present. Subjects acknowledge an interruption using this button whenever any of the ambient displays moves from the background to the foreground.

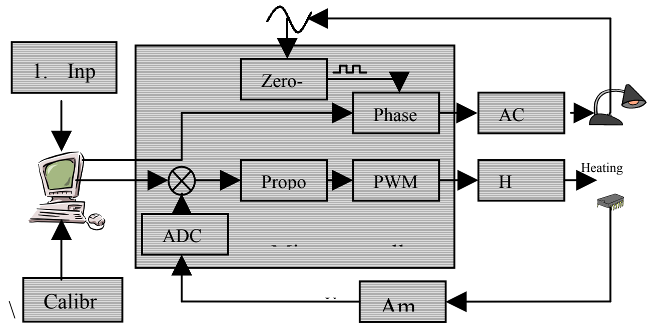

Figure 2. Thermo-mouse pad and dimming lamp proportional feedback controller.

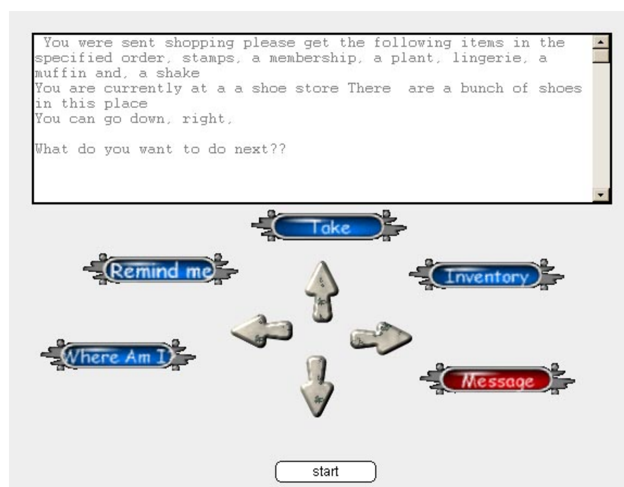

Figure 3. Graphical hybrid MUD application. Test bed for examining interruptions.

3.4 Procedure

The computer game presents subjects with a series of problems; each problem contains a list of six items to be taken in a fixed order. Miller found that fixed plans would use more working memory than flexible plans, and that fixed plans would tend to be recalled more often after interruptions [7]. Additionally, Gillie compared the effect of flexible plans with arbitrarily fixed order plans and with logical fixed order plans, and reported that people performed similarly across the three types [4]. Miller's study motivates the use of fixed order lists in this experiment and suggests that fixed lists will tend to be recalled more often. This reduces the effect of the interruption itself and increases the possibility of detecting the effect of the interruption modalities. Also, using a single fixed order reduces the number of factors involved in the experiment.

The experiment has twelve randomly presented trails; each of them contains a fixed-ordered list with six items with in the same category norm [2] each list is presented within a plausible story. For example, "You are planning to go on vacation to a foreign country and you need the following items in the specified order: brochures, some traveler's checks, a passport, a pair of sandals, a guidebook, and lotion". The list items are distributed randomly in a geographical area contained in a 5x5 matrix where subjects navigate. Once subjects have taken all six objects, the next trial is presented.

The order at which the computer presents each problem, as well as the choice of problems to interrupt are randomized. Non-interrupted problems serve as a baseline for comparison. The computer game also randomizes the interruption modality used and presents it between the fourth and fifth item. This is done with the intention of keeping subjects from expecting to be interrupted at each trial and at a specific time. Randomizing the order of presentation of the modalities also reduces any novelty effects they may cause.

Every subject performed a total of fifteen trials, three for practice and the rest as formal trials. At the end of each session, every subject produced four data sets per interruption modality: light interruption, heat interruption, and no interruption. The evaluator instructed subjects to acknowledge an interruption by clicking on the message button whenever he/she saw/felt a change in temperature/lighting conditions. After a subject acknowledges an interruption, the computer game displays a long and engaging message unrelated to the task at hand. This message is intended to disrupt subjects from their previous activity and serves as a secondary task. The evaluator instructed subjects to read the interruption message aloud and warned them that they would be presented with a free recall test at the end of the experiment (but no test was actually used). Subjects familiarized themselves with the game during three practice sessions and were allowed to ask questions when necessary.

4. RESULTS

For ease of readability, the results after evaluating the dependent variables are presented in four categories: performance, disruptiveness, effectiveness, and other measures. All of which support the hypotheses previously stated.

4.1 Performance

A One-way repeated measures ANOVA applied to the time to take each object after an interruption revealed that there is significant difference in performance caused by interruptions. The Huynh-Feldt epsilon was applied to the degrees of freedom to account for violation of the sphericity assumption, $F(1.6, 36) = 819.47$ $p<0.0005$. Pair-wise post hoc comparison reveals that there is a significant difference in performance after an interruption for non-interrupted tasks (20.32secs. per objects) Vs. interrupted tasks with heat (32.25secs. per object) and light (25.32secs. per object), $F(1,22)= 30.89$, $p<0.0005$, $F(1, 22) = 6.47$, $p<0.19$. Figure 4 illustrates a graph showing the increase in performance for each of the modalities.

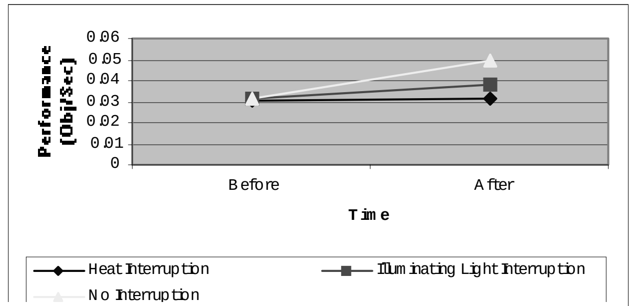

Figure 4. Performance difference for interrupted vs. non-interrupted tasks.

4.2 Disruptiveness

One-way repeated measures ANOVA applied to the number of errors in direction after an interruption for heat and light reveals that there is a main effect from interruption modality on error, $F(1, 22) = 5.478$. $p<0.029$. The error rate for heat was 0.45 errors per trial and 0.21 errors per trial for light. A one-way repeated measures ANOVA compared the number of errors before an interruption vs. after, and found there was a significant effect of interruption $F(1,45) = 19.855$ $p<0.0005$. Figure 5 shows the difference in rate of error for heat vs. light interruption..

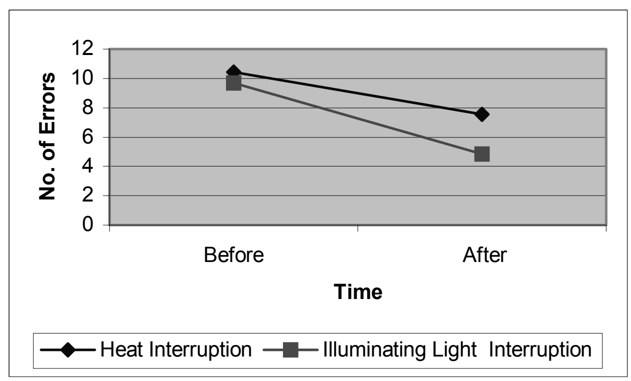

Figure 5. Difference in error rate for heat vs. light interruption.

4.3 Effectiveness

Measures of reaction time associated with the time to acknowledge an interruption were tested for differences with one-way repeated ANOVA. The analysis indicates that there was a significant difference in reaction timed for heat (9.60secs.) and light (5.50secs.), $F(1, 22) = 7.76$, $p<.011$.

4.4 Preferred Modality

Subjects were asked to choose their preferred modality subjectively. 40% of the subjects selected heat as their preferred modality, and the remaining 60% of the subjects selected light. One-way repeated measures ANOVA shows there is no main effect of preferred modality in performance difference, $F(1,22) = 1.374$, $p>.254$, and neither in speed, $F(1,22)= .006$, $p>.94$.

4.5 Observations

One surprising comment about heat was the fear of being hurt. In general heat was perceived as a dangerous threat. It was also generally mentioned that heat is slower than light, and thus harder to detect. Interestingly, although heat was harder to detect, it was also harder to ignore once it was present. This is probably due to the fact that subjects associate heat with danger, and as a consequence, did not dare ignore it, anticipating being burned. Alternatively, light could be postponed until the task at hand had finished. Light, as opposed to heat, which had an affective component, had no physical interaction with subjects that could be perceived as an invasion their own personal space.

39% of subjects agreed that light is easier to identify than heat. There were mixed comments about how disruptive light is, some mentioned light is more disruptive and others mentioned light is less disruptive. There were only 8% of subjects classifying light as pleasant. There were mixed comments about how disruptive heat is, 50% of subjects classified heat as more distracting or disruptive, whereas the other 50% classified heat as less distracting and less obtrusive. Some subjects even mentioned heat as pleasant, especially in cold environment or as an aid for carpal tunnel syndrome treatment.

5. DISCUSSION

The hypothesis stating that the type of modality used to interrupt has different effects on performance was verified. Performance, measured by the time to take objects, indicates that there is a 24% increase in performance when interrupting with light and only a 2% increase in performance when interrupting with heat. Performance, measured by speed, indicates that there is a significant effect caused by an interruption, but not a significant difference between modalities. There is a 5.3% decrease in performance when interrupting with heat and a 7.6% decrease when interrupting with light. From these results it is clear that using heat as an interruption modality has a larger detrimental effect on the performance; determined by both measures of the task being interrupted than light. It is possible that heat was perceived as a threat, and the threat of being hurt could have stressed subjects. As a consequence, this could be an external factor that causes differences in performance in heat and light.

The hypothesis that disruptiveness changes with the type of modality was partially verified. There is no significant effect from interruptions in error in objects taken, help requested, or recover time as measures of disruption. Disruptiveness, measured by the number of reminders requested before an after an interruption, shows that there is no difference between heat or light modalities. Nevertheless, there is a main effect of the interruption itself, resulting in a reduced number of reminders after an interruption. Regarding errors in direction as a measure of disruptiveness, light seems to reduce the number of errors in direction by 50%, whereas heat reduces them by only 37%. According to this result, heat has a greater disruptive effect than light. Measures of disruptiveness should be interpreted with caution because there was an unexpected significant difference in the number of errors before an interruption. However, taking into account that there was a significant effect on interruption and the fact that this result agrees with the previous hypothesis in that heat has a greater effect on performance than light, its plausible that these findings are valid.

The hypothesis stating light is more effective as an interruption modality than heat was verified. Based on the time necessary for acknowledging, light was about 42% faster than heat. Thus, it is more effective for getting the user's attention promptly. Theory indicates that reaction times for heat and light should have been faster. There are three possible explanations for this result: 1) subjects were highly engaged in performing the task and took longer to notice the visual and thermal stimuli, 2) Subjects postponed acknowledgement of an interruption until they were done with a specific section of their current task. 3) A combination of the two. Observations of trial sessions indicate that in some cases subjects were really engaged in the task and did not notice the stimuli for some time after it appeared, in other cases subjects specifically mentioned that they finished their current activity before acknowledging the interruption. The same type of subjects also mentioned that the thermal stimulus prevented them from doing so, which could explain for the decrease on performance when interrupting with heat (subjects had to immediately stop their activity to acknowledge a heat interruption and forgot the details of their current task, whereas light was easier to postpone).

The alternative hypothesis stating that subjects will be negatively affected by their non-preferred modality could not be verified. There was no main effect of subject's preferred modality in performance, neither was an effect in speed. 60% of subjects selected light as their preferred modality, and the other 40% chose heat as their preferred modality.

This experiment verifies previous research about interruptions, in that subjects perform slower on an interrupted task than on a non-interrupted task, demonstrating the general effect of interruptions. Furthermore, this experiment also shows that the interruption modality affects performance. The thermal display produced a larger decrease in performance than the visual display. This thermal display also has a greater disruptive effect on the interrupted task than light. Disruptiveness and performance measures agree that heat causes more of a detrimental effect than light when used as an interruption.

We learn many things from these results in terms of how to use these two modalities of interruption. This work shows that light is more efficient in getting user's attention (42% faster than heat). Light has a disruptive side effect on speed (24% slower than uninterrupted); which is slightly larger than the effect from heat. In contrast, heat takes longer to be noticed. Heat could be used more reliably in environments where other channels are already saturated or overwhelmed with information (i.e., when there are many visual distractions). One of the advantages of using heat is that users be interrupted without taking their attention off the screen. Whereas with light, users tend to focus their attention to the light source. Additionally, heat is an interruption to a single person, without disrupting everyone around them. Unlike ambient lights, which alert all people present at the location where light changes occur, heat can be used to signal messages subtly to a single person, Therefore heat is a personalized attention-getting device.

The factors that had a statistical effect on performance are speed and time to take an object (success rate). The factors that had a statistical effect on disruptiveness are the number of errors in direction and reminders. The factor that had a statistical effect on effectiveness is reaction time; the time necessary to acknowledge an interruption. These factors could be used by an adaptive interface to compare the effect of different modalities in every user. By taking these results and applying them to user interface design, a system could maximize the effectiveness of interruptions through proper modality arbitration.

6. CONCLUSION

This work contributes to previous research by showing there is an effect on performance caused by interruption modality. Thermal modality produced a larger decrease in performance than visual modality and has a greater disruptive effect on interrupted tasks than light. Disruptiveness and performance measures agree that heat causes more of a detrimental effect than light when used as an interruption. The general effect of interruptions was demonstrated; subjects perform slower on an interrupted task than on a non-interrupted task.

Even though work has been done on the area of adaptive user interfaces [8, 11], they do not consider adapting the output modality itself. Our results suggest it is possible to build a multimodal interface that will employ users' individual physiological responses to each modality and dynamically select the interruption modality based on effectiveness and performance metrics.

Thus it is conceivable to maximize the effectiveness of an interruption through proper modality selection and configuration. Future systems hold the promise of becoming multimodal self-adaptive interfaces, receiving physiological feedback about disruptive effects of an interruption modality and using this feedback to adapt output modalities themselves.

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