Arbitrating Multimodal Outputs: Using Ambient Displays as Interruptions

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Abstract

This work explores the use of ambient displays in the context of interruption. A multimodal interface was created to interrupt users using ambient displays in the form of heat and light. These ambient displays acted as external interruption generators. Experimental results show there are different effects on performance and disruptiveness caused by interruption modalities. Thermal interruptions have a larger detrimental effect than light interruptions on disruptiveness and performance. These results offer guidelines for interface designers to help them select interaction modalities to accommodate people's limitations relative to focus, concentration and interruptions. Furthermore, this work also shows that it is possible to differentiate between modalities and create multimodal interfaces that arbitrate between interruption modalities based on their effectiveness, user's performance, and disruptive effects.

1 Introduction

The use of interruptions is key in the design of human-computer interfaces. In general, current computer environments are becoming more and more complex, with an increasing number of tasks and an increasing number of events computer users have to keep track of (Maes, 1994). Multitasking is useful and natural. Unfortunately people have cognitive limitations that make them susceptible to errors when interrupted (McFarlane, 1999). Researchers have investigated interruptions by looking at how and when to interrupt users in a multitasking environment (McFarlane, 1999 & Czerwinski, 2000). They have also found that users perform slower on an interrupted task than on an uninterrupted task; that is, interruptions are perceived as disruptive. This work identifies key factors that influence the perceived effect of two interrupting modalities and shows the effect of two different interruption modalities on performance and disruptiveness.

Multimodal interfaces provide substantial advantages in efficiency (Oviat & Cohen, 2000). Finger and hand actions with the keyboard and mouse are commonly used to communicate to the computer. Visual and acoustic modalities are the most often used for conveying/presenting information to the user (Srinivasan, 1995 & Tan, Ifung & Pentland, 1997). Current human computer interfaces generally ignore important modalities such as ambient and peripheral visual cues, heat, vibration, smell and the sense of touch. The main focus of multimodal HCI research has been on combining input modalities rather than using multimodal outputs to take advantage of human sensing capabilities. 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.

This work shows that the disruptiveness and effectiveness of interruptions varies with interruption modality. A multimodal interface was created with two ambient displays for interruption: heat and light. User awareness of these ambient displays shifts from the background to the foreground (Wisneski & Ishi, 1998), acting as external interruption generators. Overall, the thermal modality produced a larger decrease in performance and disruptiveness on a task than the visual modality.

2 Approach

This work explores the use of ambient displays in the context of interruption. Ambient displays present information in the modality and form that can be interpreted with a minimal cognitive effort (Wisneski & Ishi, 1998). Ambient displays act as external interruption generators designed to get users' attention away from their current task; they also serve as a media for interruptions.
This paper presents an experiment designed to test the effect of heat and light when used as interruptions. The experiment purpose is to identify the key factors that influence what are the perceived effects for each ambient display.

Interruption involves many subtle low-level mechanisms of human cognition (Bailey, Konstan & Carlis, 2000). In order to study the effects of interruptions, a simplified abstract model of common real world tasks was chosen. The task involves a graphical-textual computer-based game that imposes a high cognitive load (See Figure 1). 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. These identification and tracking tasks impose a high cognitive load. Interruptions during this process cause errors, allowing for observations of subjects' responses to be easily broken down into discrete units (Gillie & Broadbent, 1989).

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 in order to achieve certain goals. Gillie, et al used a similar approach (Gillie & Broadbent, 1989). A MUD is a network-accessible, multi-participant, user-extensible game in which participants have the appearance of being situated in an artificially constructed place through an entirely textual interface.

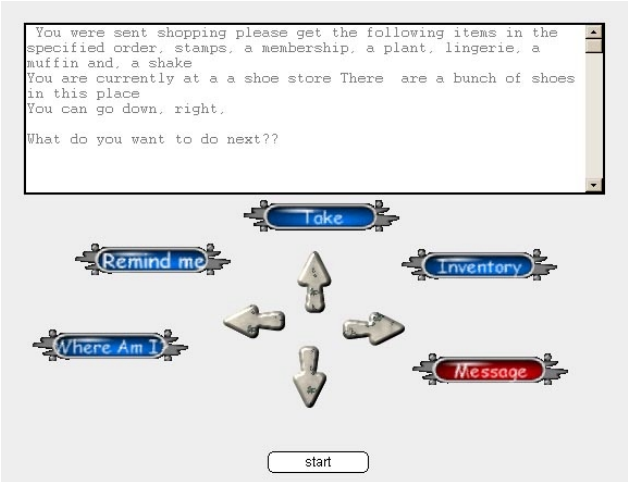

Figure 1: **Graphical-textual computer-based game**

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 (Czerwinski, 2000).

2.1 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.

2.2 Procedure

The experiment has twelve randomly presented trails; each of them contains a fixed-ordered list with six items with in the same category norm (Battig, & Montague, 1969) presented within a plausible story. 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. While subjects perform the primary task, an ambient device attracts their attention by changing temperature or light intensity. Subjects then acknowledge the interruption and read a list of words organized into networks of associated ideas. This dual-task of the experiment is conceptually simple, but difficult to perform due to the high cognitive load.

The order in which the computer presents each problem, the interruption modality to use, as well as the choice of problems to interrupt are randomized. Randomizing keeps subjects from anticipating interruption and balances any novelty effects interrupting modalities may cause. Non-interrupted sessions serve as a baseline for comparison.

3 Results

Heat presented a larger detrimental effect on performance than light. Performance measured by the time to take objects compared against a non-interrupted session, indicates that there is a 24% increase in performance when interrupting with light, $F(1,22)=6.47$, $p<0.019$ and only a 2% increase when interrupting with heat, $F(1,22)=30.89$, $p<0.0005$.

Heat presented a greater disruptive effect than light. Disruptiveness, measured by errors in direction, indicates that light reduces the number of errors by 50%, $F(1,22)=7.23$, $p<0.013$, whereas heat reduces them by only 37%, $F(1,22)=12.757$, $p<0.002$.

Light is more effective for getting user's attention promptly. Light was noticed 42% faster than heat $F(1,22)=7.76$, $p<0.011$.

Subjects were not negatively affected by their non-preferred modality. Based on subjects self-reported preferred modality, there was no main effect of subject's preferred modality in performance $F(1,22)=1.374$, $p>0.254$, neither was an effect in speed observed $F(1,22)=0.006$, $p>0.94$.

Although heat was harder to detect, it was also harder to ignore once it was present. Heat was perceived as a dangerous threat. 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.

3.1 Discussion

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 larger of a detrimental effect than light when used as an interruption.

Advances in computer technologies have enabled the creation of systems that allow people to perform multiple activities at the same time. People have cognitive limitations that make them susceptible to errors when interrupted. Unfortunately, interruptions are common to today's multitasking computing user interface experience. Computer interfaces must be designed to accommodate people's limitations relative to focus, concentration and interruptions. These results offer guidelines for interface designers in choosing one modality over the other. Light is more efficient in getting user's attention (42% faster than heat). In contrast, heat takes longer to be noticed but is more disruptive. Heat could be used more reliably in environments where other channels are already saturated overwhelmed with information (i.e., when there are many visual distractions). One advantage of using heat is that users can be interrupted without taking their attention off the screen. With light, users tend to focus their attention to the light source. Additionally, heat is an interruption to a single person; a personalized attention-grabbing device. 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-grabbing device. By taking these results and applying them to user interface design, a system could maximize the effectiveness of interruptions through proper modality arbitration.

4 Conclusion

This work explored the use of ambient displays in the context of interruption in order to illustrate the use of other perceptual channels in current computer interfaces. A multimodal interface was created to interrupt users using ambient displays in the form of heat and light. These ambient displays acted as external interruption generators. Ambient displays can help orient and situate a person to serve a purpose other than the mere presentation of information—they can serve as a media for creating and changing context about interruptions.

This works contributes to previous research by showing there are different effects on performance and disruptiveness caused by interruption modalities. Thermal interruption has a larger detrimental effect on both disruptiveness and performance. Previous research regarding the general effect of interruptions, in which subjects perform slower on an interrupted task than on a non-interrupted task, was also corroborated.

Human senses differ in their ability to be ignored, precision and speed. The common and unique characteristics of the human senses allow for the design of an interface that uses multiple

modalities and, furthermore, of an interface that selects the modality to use based on contextual information. We have shown that it is possible to differentiate between modalities and build multimodal interfaces that select the interruption modality to use based on its effectiveness, user's performance, and disruptive effects. We can now work to improve interfaces that arbitrate between interruption modalities.

We envision utilizing users' physiological responses as feedback to a computer interface, so that the interface could modify the way it communicates with every user by selecting and configuring the adequate modality. Our experiment sets the initial point for understanding how to build interfaces of this type by looking at the effect of different modalities when used as interruptions.

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