Ergonomic evaluation of ubiquitous computing with monocular head-mounted display

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ABSTRACT

In this paper, the authors conducted an experiment to evaluate the UX in an actual outdoor environment, assuming the casual use of monocular HMD to view video content while short walking. In conducting the experiment, eight subjects were asked to view news videos on a monocular HMD while walking through a large shopping mall. Two types of monocular HMDs and a hand-held media player were used, and the psycho-physiological responses of the subjects were measured before, during, and after the experiment. The VSQ, SSQ and NASA-TLX were used to assess the subjective workloads and symptoms. The objective indexes were heart rate and stride and a video recording of the environment in front of the subject’s face. The results revealed differences between the two types of monocular HMDs as well as between the monocular HMDs and other conditions. Differences between the types of monocular HMDs may have been due to screen vibration during walking, and it was considered as a major factor in the UX in terms of the workload. Future experiments to be conducted in other locations will have higher cognitive loads in order to study the performance and the situation awareness to actual and media environments.

Keywords: monocular HMD, user experience, outdoor environment, VSQ, SSQ, NASA-TLX, heart rate, walking speed

1. INTRODUCTION

Monocular head-mounted display (HMD) is a type of wearable device designed to provide visual information in a ubiquitous environment. The use of a monocular HMD to receive two different types of visual data - data on the real environment and data from a media environment - is expected to enable more advanced judgments and activities. Monocular HMD has been studied for application as helmet-mounted display for use in helicopters1-2 as well as use in maintenance3, medicine4, firefighting5, air traffic control6 and so on. There have also been several studies7-8 on increasing the performance with a monocular HMD in these fields of application. The negative aspects that come along with receiving different information in the left and right eyes, too, are a concern with regard to a monocular HMD. These include the occurrence of binocular rivalry, the effect on visual awareness9-10, visual fatigue and discomfort11.

In recent years, monocular HMDs have become more compact and lightweight, with improved image quality and reduced cost, and some consumer-oriented products have appeared on the market. Unlike the abovementioned specialized fields of application, casual use of monocular HMDs might find application in various situations such as viewing video content in outdoor settings12. In this way, although monocular HMDs are already at the stage of practical application, they have not yet been adequately studied empirically from a user's perspective. Such efforts have been limited to several related case studies, such as subjective assessments conducted in a laboratory using a binocular HMD13. In other words, despite technical maturation and the establishment of the concept, the usability, usefulness etc. of the casual use of a monocular HMD is still unclear, and this may be one factor hindering their widespread use. In this study, the authors conducted an experiment on the user experience (UX) in an actual outdoor environment assuming the casual use of a monocular HMD to view video content.
2. PURPOSE

The purpose of this study is to conduct a psycho-physiological evaluation of a monocular HMD in an actual outdoor environment. As it is easy to maintain control in the laboratory, the causal relationship between experimental conditions and results can be studied with precision. In outdoor environments, however, multiple factors are concerned in complex ways, and these are thought to be reflected in the results. Accordingly, for the purpose of this study, the equipment and tasks were made as simple as possible, in order to obtain the basic characteristics of the psycho-physiological changes caused through the use of a monocular HMD in an actual environment.

3. METHODS

3.1 Conditions

Four different conditions for the stimulation were prepared. In Condition 1, stimulation was provided using a monocular HMD (Nikon, UP 300x) fastened to the head by means of an arm bar and headphones. In Condition 2, a monocular HMD (Arisawa, i-Bean) was fastened to goggles worn by the subject. In both cases, the monocular HMD was attached to the dominant eye of the subject as determined based on the results of a hole-in-the-card test. In Condition 3, for purposes of comparison with the monocular HMD, stimulation was provided by means of a hand-held media player (Apple, iPod 5G). Condition 4 was the control status in which tasks were performed without stimulation.

<table>
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<tr>
<th>Table 1. Specifications for the two types of monocular HMD</th>
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<td><strong>Condition</strong></td>
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<td>Virtual distance and screen size</td>
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<td>Weight</td>
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Figure 1. UP 300x (left) and i-Bean (right).

3.2 Tasks

As the tasks to be performed, the subjects were asked short walking through a large shopping mall in the center of Helsinki, Finland while wearing a monocular HMD and perceiving visual stimulation. The total distance walked was approximately 600 meters. Subjects were asked to use the escalator when moving between floors, in order to reduce the effect of changes in walking condition on their physiological responses.
3.3 Stimulation
The audio-visual stimulation provided to subjects comprised three types of news video. These were edited and encoded to approximately ten minutes, in accordance with the time required to accomplish the tasks, and provided in random order. In order to confirm the attention paid by the subjects to the stimulation, questions regarding the content of the news video were given to the subjects following each trial. The subjects were informed before each trial that they would be asked questions regarding the content.

3.4 Subjects
There were a total of eight subjects, seven males and one female, ranging in age from their 20s to 40s (the average was 32.9 years of age). Their visual acuity in binocular was 1.0 or greater without / with correction, and their stereovision was confirmed by means of the Randot Stereotest. Subjects were provided with a thorough explanation regarding the purpose and the methods, and their consent was obtained prior to the experiment.

3.5 Subjective indexes
The subjective indexes for the experiment were measured using a Visual Symptoms Questionnaire (VSQ) and a Simulator Sickness Questionnaire (SSQ) both before and after each trial, and using a task load index (NASA-TLX) after each trial. Moreover, after the trials under Conditions 1 through 3, an interview was conducted to determine how the subject felt while using the equipment and so on.

The VSQ16 is a questionnaire for the purpose of assessing visual symptoms, to which subjects provided responses on a four-point scale. The SSQ17 is a questionnaire designed to determine simulator sickness based on three components (nausea, oculomotor and disorientation). The sum of these three components represents the total SSQ score. The NASA-TLX18 is a method for evaluating workload with regard to tasks. In the NASA-TLX, six weighted subscales (mental demands, physical demands, temporal demands, own performance, effort and frustration) are combined to determine the total workload score. All of these indexes are often used for evaluating media interfaces13.

3.6 Objective indexes
As objective indexes, the heart rate and walking speed of the subject were measured during each trial, and the environment in front of the subject's face was video-recorded.
The heart rate shows the response to psychological and physical load. Walking speed is an index that is closely related to the tasks in this experiment. These indexes were recorded by means of a wristwatch-type module (Polar, 800sd) that synchronizes and integrates the data from the heart rate and stride sensor. Video-recording the environment in front of the face during each trial enabled to determine whether the changes in heart rate and stride length were caused by the conditions or the surrounding environment. A small camera mounted to the center of the goggles video-recorded the environment in front of the subject's face. The videos were saved on a pocket-sized video recorder (Sun-Mechatronics, Police Video 700 HC) through a 12 V camera AV cable. All of these units are compact and lightweight, and they are thought to be appropriate for use in outdoor environments such as the one in this experiment.

![Figure 3. Layout of experiment under Condition 1.](image)

3.7 Procedure

Before the experiment, the experimenters explained the procedure to the subjects and then obtained their responses to the VSQ and SSQ questionnaires as subjective indexes. Next, the subjects donned wristwatch-type modules, heart rate sensors attached to their chests, stride sensors attached to their shoelaces and goggles-mounted-cameras. For Condition 1 and Condition 2, the subjects were provided with monocular HMD; for Condition 3, they carried hand-held media players.

Following abovementioned preparations, the subjects walked through the shopping mall and performed tasks in accordance with the instructions given by the experimenters. When the tasks had been completed, the responses of the subjects to the VSQ, SSQ, NASA-TLX and interviews were obtained. The trials were provided in random order and conducted individually. As objective indexes, the heart rate and walking speed of the subject were measured during each trial, and the environment in front of the subject's face was video-recorded.

4. RESULTS

4.1 Subjective indexes

Four subjective indexes were employed: the VSQ, the SSQ, the NASA-TLX and the interviews. The results for each are shown below. The response rate with regard to the questions on stimulation content was 79.4% for Condition 1, 72.6% for Condition 2 and 83.0% for Condition 3. The order effect between the trials was not found.

(1) VSQ

Figure 4 shows the VSQ results for each condition, converted into the change from the baseline score measured prior to the trials. There was an increase in the score when the monocular HMD was used, and the analysis of variance (ANOVA) revealed a marginal significance (p < .10).
(2) SSQ
The results of the SSQ for each condition are shown in Figure 5. As in the case of the VSQ, the score prior to the trials was used as a baseline and the change was noted in the figure. Although these results showed the same trend as the VSQ results, the ANOVA did not indicate significance. There was also no significance for any of the components (nausea, oculomotor and disorientation).

(3) NASA-TLX
Figure 6 shows the total workload score for each condition. The ANOVA indicated significance (P < .01). With regard to the subscales, significances were also noted for mental demands (P < .01), physical demands (P < .05), effort (P < .01) and frustration (P < .01). These subscales showed the same tendency as the total workload score with regard to the differences in terms of conditions.
(4) Interviews
The major comments expressed in the interviews for each condition are shown in Table 2.

| Condition 1 | “The image quality is good, but it's difficult to read characters.” "The good thing is that it's wireless so I have both hands free.” "The field of view of the dominant eye is reduced, so you have to be careful while walking.” | * Opinions regarding the fit of the headphones on the head were divided between those who thought it was too tight and those who thought it was a stable fit. |
| Condition 2 | “Visibility is good as long as you're standing still, but it's not suitable for observing things while walking.” "It's difficult to keep the screen stable while walking.” "The cable is bothersome and it prevents me from concentrating on the screen.” "The size is just right, so it's suitable for use while you're sitting in a car driving and so on.” |
| Condition 3 | “Since it's a hand-held unit, it's easy to control.” "The video is not always right in front of you, so depending on the content you can choose whether or not to look at it.” "It's difficult to pay attention when you're trying to do two or more things at the same time.” |

4.2 Objective indexes
Three objective indexes were measured: heart rate, walking speed and the environment in front of the subject. The results for each objective index are shown below. With regard to heart rate and walking speed, areas 1 through 3 in Figure 2, not including movement between floors, were extracted and analyzed. The average required time by the subject to complete the tasks was approximately 7 minutes 20 seconds. The order effect between the trials was not found.

(1) Heart rate
Figure 7 shows the mean heart rate for each condition. Both heart rate and walking speed were measured every five seconds. The ANOVA indicated a significance (P < .01), and there was a notable difference between Conditions 1 and 2 in which the monocular HMDs were used.
(2) Walking speed

Figure 8 shows the mean walking speed for each condition. Walking speed was measured using the acceleration of the subject's foot, to which a stride sensor had been attached. The ANOVA noted significance ($P < .01$). The walking speed was lower in the case of the conditions in which the monocular HMDs were used.

(3) Sight switching

From the video that recorded the environment in front of the subject's face, it was confirmed that there were no notable changes in congestion level or other unusual events. The video content was quantified in terms of the number of the subject's sight switched between looking forward and looking downward, and the results for each condition are shown in Figure 9. The ANOVA showed a significance ($P < .01$), and the subject's sight was frequently switched to his or her hands in the condition 3 in which the hand-held media player was used.
5. CONCLUSIONS

In this study, an experiment was conducted to evaluate the UX in an actual outdoor environment, assuming the casual use of monocular HMD to view video content while short walking. In conducting the experiment, the equipment and tasks were designed as simple as possible in order to determine the basic characteristics of the psycho-physiological changes through the use of monocular HMD in an actual environment.

The results of the subjective indexes showed consistent tendencies. Taken together, the VSQ, SSQ and NASA-TLX results are thought to indicate that the visual symptoms influenced as a major workload. When the interviews are considered together with the results, it appears that the stability of the screen, which was affected by vibrations during walking, may be one factor accounting for the significant workload found in Condition 2. The heart rate, one of the objective indexes, also tends to support the results for the subjective indexes, and it is thought that it reflects the visual workload due to the unstable screen. In terms of the results for the other objective indexes, walking speed decreased and the sight was maintained in the forward direction when the monocular HMD was used. This suggests that subjects were walking with care because they were using an unfamiliar device, but they were not looking down frequently to check their footing. Moreover, it is also considered that the low heart rate for Condition 1 was affected by the low walking speed and the low frequency of the sight switching.

These results suggest that, in this experiment, the workload in terms of visual symptoms was significant in the UX with a monocular HMD, and the subjective and objective indexes corresponded with regard to this point. They also suggest that, in order to improve the UX, it is important to have a design that is able to balance visual awareness to the actual environment with device mounting stability. In other words, if additional experiments are conducted using a monocular HMD with improved visibility and stability, and if the degree to which the subject is accustomed to the equipment is taken into account, it is expected that the differences between conditions will be reduced.

With regard to future issues for study, additional experiments should be conducted in various locations; for example, inside a train in Tokyo, Japan. In terms of tasks, the authors plan to use higher cognitive loads, such as navigation route changes and interactive gaming, in order to study the performance and the situation awareness to actual and media environments.
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