Physical Visual Effects for the Use of Head Mounted Display

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Received 15 June 2001 ; Accepted 16 August 2001

Abstract

Head Mounted Display (HMD) is a delicate and convenient display system. It can replace some widely used TV and CRT monitor of the computer, and display devices of the entertainment products. There is rear information of the physical visual effect of the user to be studied in detail after continuous long time wearing the HMD. And, only a few reports indicate some uncomfortable evidences of the use of HMD, even thought the issue is an important factor for the HMD user. This paper presents a human visual testing design for studying the physical visual effects of the use of HMD comparing with that of watching on TV monitor. One test is the measurements of electro-oculography, EOG, for tracking a moving target displaying on the HMD and the TV monitor to compare the degree of the eye muscle tiredness. The second test is the measurements of user Inter-Pupillary Distance, IPD, after the use of HMD based on different target tracking test. All the tests also record the corresponding user questionnaires. Results indicate that the use of HMD do have physical visual effects and some uncomfortable evidences for continuous long time watching on the HMD screen. The paper will provide all the detail information of the results and conclusions for the HMD users. The new product designers in the HMD industry may also obtain some information in this study to develop more reliable HMD in the future.

Keywords: Head Mounted Display, Visual effect, Visual safety analysis

Introduction

Eyes are one of the most important sensing organs to receive outer massages. In order to realistically present the true environment seeing to the human visions, there are many different display technologies developed [1]. Nowadays, head-mounted display, HMD, has been developed to a delicate and convenient display system. It can be widely applied to TV, CRT monitor of the computer, and LCD of the notebook. Speaking in functions, HMD has unique three-dimensional display function, which provides virtual reality development of main equipment. Beside this, it can also be developed to computers, video machines, and other vision products. The HMD system will be one of important items in consumer electronic products with various new applications in the future. [2][3].

The first generation of HMD was designed by Ivan Sutherland in 1965 [4]. Then, HMD is laid more emphatic. Although there are many researchers and electronic companies trying to use HMD to replace TV as a new display device, it doesn't have a final conclusion about how to position HMD well in consumptive electro-commodities. One of the primary questions is: does the use of HMD have any effects on human bodies, and what kind of physical functions will be affected? Several studies had ever pointed out that if we made a study in two different virtual realities, and one made by two-dimensional images and the other by three-dimensional images, then asked the testers to observe the image in the screen for ten minutes. The results showed that the testers observed three-dimensional images had a predominant increase in burdens of visual functions and felt some uncomfortable syndromes such as dizziness [1]. Another study reveals that if the Inter-Pupillary Distance, IPD, between two eyes differs too much from the system IPD of HMD, it would cause a temporary and exhausting state of visual system. The study concluded that the HMD with an adjustable system IPD design is expected [5]-[6]. Some other related studies revealed that there were ever some users whom felt eyes exhausting, shoulder ached, and dizzy after the use of HMD for a long time [2] [3].

HMD may be a developing direction of consumptive electro-technology in the future, but it has not been spread into every family to be widely used until now. Partial reason

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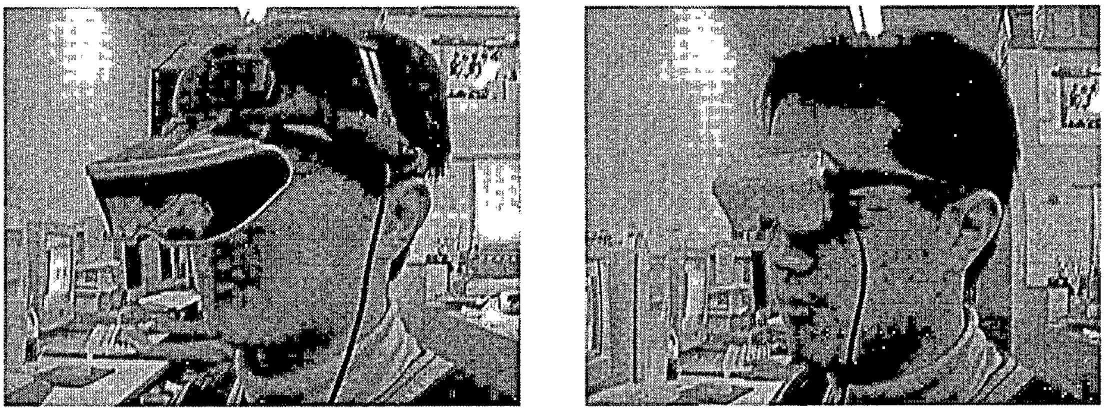


(a) (b)

Figure 1. The pictures of two HMDs used in this study. (a) Sony PLM-50 model, and (b) Olympus FMD-150W Eye type of Eye-Trek model.

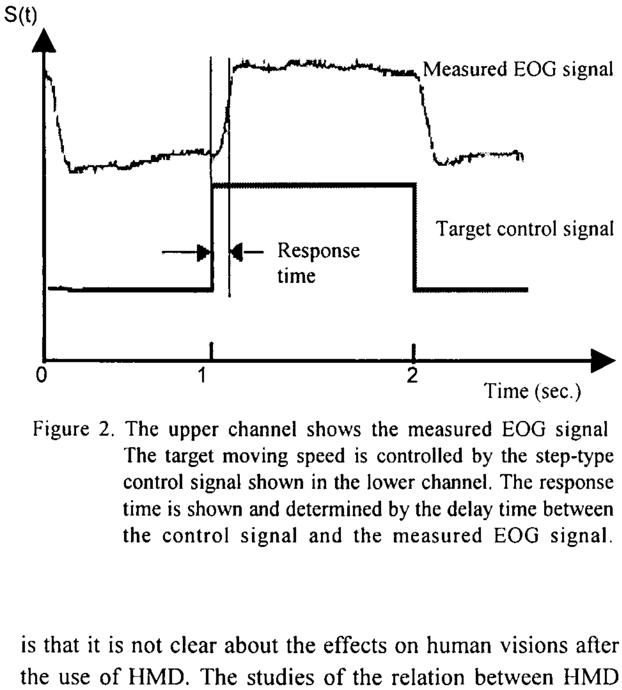


Figure 2. The upper channel shows the measured EOG signal The target moving speed is controlled by the step-type control signal shown in the lower channel. The response time is shown and determined by the delay time between the control signal and the measured EOG signal.

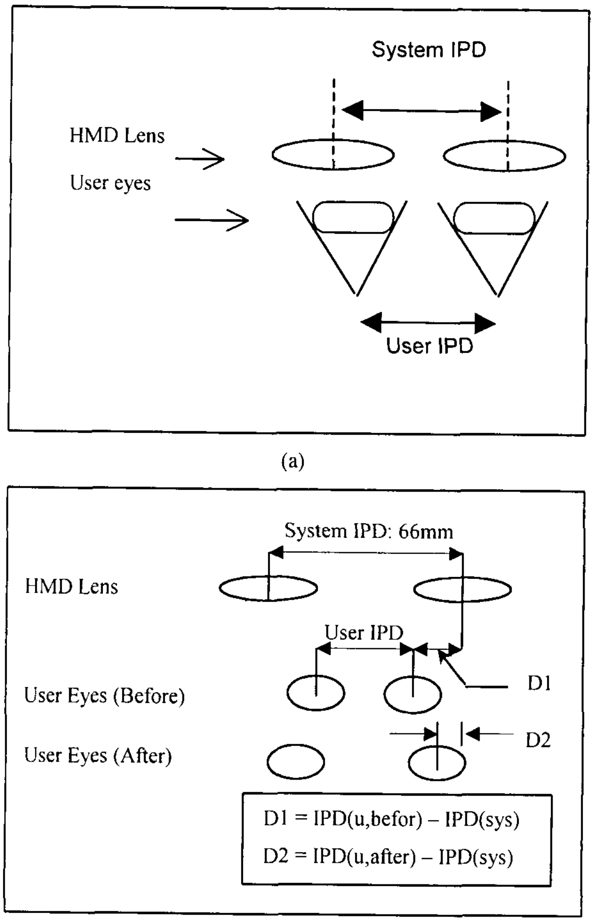
is that it is not clear about the effects on human visions after the use of HMD. The studies of the relation between HMD and human health are still less and only a few related experimental reports that can be referred for helping to design a new HMD system. The purpose of this study is to aim at the visual exhausting state and to analyze it after the use of HM. We expect to exam deeply about the different physical responses in different visual situations. The experiment tests will be described in the next section. The third section is the results of the tests. Some conclusions of the use of HME are given in the last section.

Methods

In this study, two LCD types of HMD (Sony PLM-50 HMD and Olympus FMD-150W HMD) and one 17in high-resolution computer monitor were employed. The important system specifications of Sony PLM-50 and Olympus FND-150W HMD are 640*480 pixels and 640*380 pixels for spatial resolution, 23° ∗ 18.5° and 37.5° ∗ 21.7° for system visual angles, and 300g and 110g for the total weights, respectively. The IPD of the both HMDs is fixed in 66mm. Figure 1 shows the wearing pictures of the user in reality of the two HMDs.

In order to measure the tiredness of visual conditions after the use of HMD, we will measure and analyze the electric signals of eye muscles which control eye movement, namely electro-oculography (EOG) recorded in real time during the use of HMD for the visual tracking study [7]-[8]. Measured user IPDs and the questionnaire surveying of visual exhausting state will be recorded before, in middle, and after the use of HMD. In this study, six male and four female volunteers were invited to do three tests including watching two simulation target movements for five minutes based on three different display devices that were regular TV monitor and the above two HMDs. The ten volunteers are normal in eyes and 22 years old in average.

The first test was designed for understanding the effects of the visual situation after tracking a moving target on the display screen continuously for at least five minutes. This study asked testers to track the target shown on the display screen at the right and left side one at a time alternately. Each tester need to trace the target five minutes under three different target moving rhythms which were 200ms, 500ms, 1000ms. Of course, the testers always had at least thirty minutes rest before each test. For the post analysis purpose, two channels, one step-type signal for controlling the target movement and one EOG signal of user on tracking the target, were real-time recorded during each complete test. The EOG recording system was implemented by 89C51 microprocessor-based design with transporting data by the UART, and transporting data into the computer by RS232. Figure 2 shows the typical measured EOG signal and its corresponding target control signal.



(b)

Figure 3. An illustration of (a) IPD measurement, and (b) the definition of the two major parameters, D1 and D2. The ratio of D1 and D2 presents the degree of the total effects of the user IPD before and after the use of HMD. The ratio value shall be equal to one if there is no any effect of the user IPD.

The main purpose of the first test is to simulate the basic responses of user when playing video games by HMD. Each tester traced target moving in different velocities that may cause the visual system to response its physical situations in the measured EOG, and can be used to estimate the effect of the use of HMD. We define the response time, which is based on the delay time between the measured EOG signal and the control signal. The response time is also illustrated in figure 2. After continuously tracking the target on the display screens, the parameter of the response time may effectively represent the dynamic tracking abilities of the tester, especially at the late tracking time. The longer the response time represents the more visual exhausting of the tester, and it means that the tester is hard to follow the moving speed of the target on the display screen.

In additions, all testers will measure their user IPD at normal resting state, i.e before the test. After each test, the user IPD will be immediately measured for comparing the differences between before and after the use of HMD. We also defined an evaluation factor based on the ratio of the differences of the system IPD and user IPD before and after the use of HMD. Figure 3 is the illustration of the evaluation factor resulting from the use of HMD to assess the feasible effects when the user IPD is different from the system IPD. The D1 parameter is the absolute difference between user IPD at normal resting state and the system IPD of HMD. The D2 parameter is the absolute difference between user IPD after the use of HMD and the system IPD of HMD. Using the D1 and D2 parameters, we can define a hypothesis to allow us to understand whether the physical visual effect exist, if the user IPD would approach to the system IPD after the use of HMD. The effect will be considered as a positive effect when the following hypothesis is success, that is

Hypothesis: Positive effect
when (I) Hypothesize $D1>0$ and $D2<0$
or (II) Hypothesize $D1<0$ and $D2>0$,

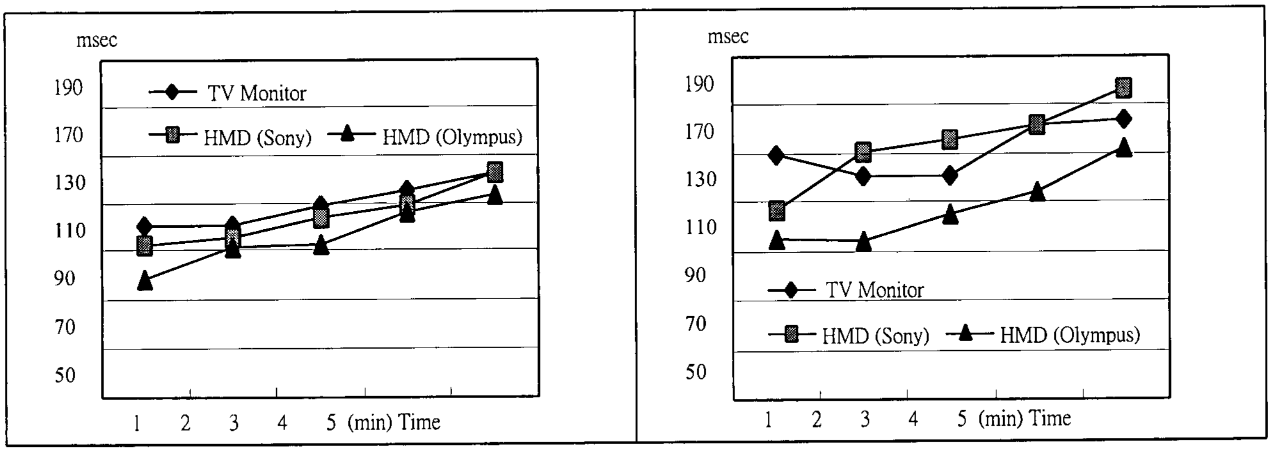
In general conditions, if the user IPD between two eyes differ too much from the system IPD, it would cause a temporary exhausting state of visual system, or result in medial or lateral strabismus. For example, if the system IPD is greater than the user IPD, eyes muscles must contract abnormally to make eyeballs turn toward the temporal side, then images in the screen could be accepted normally and it would cause lateral strabismus. Oppositely, if the system IPD is smaller than the user IPD, it would cause medial strabismus easily. Therefore, we especially bring up this idea in the study and compare the results obtained from the response time of the EOG signals. In all studies, the user IPD was measured by an ophthalmological instrument, Canon Tonometer Tx-10. The ratio value of the IPD effect factor shall be less than one. The more the effect of the use of HMD is, the less of the ratio value presents.

Results

In order to make sure that the tester indeed follows the target's movements, testers should read aloud what letters of alphabet recognized in the target when the target moved in a fixed velocity but changed the letter of alphabet in it. The procedures of test-1 are shown in the following:

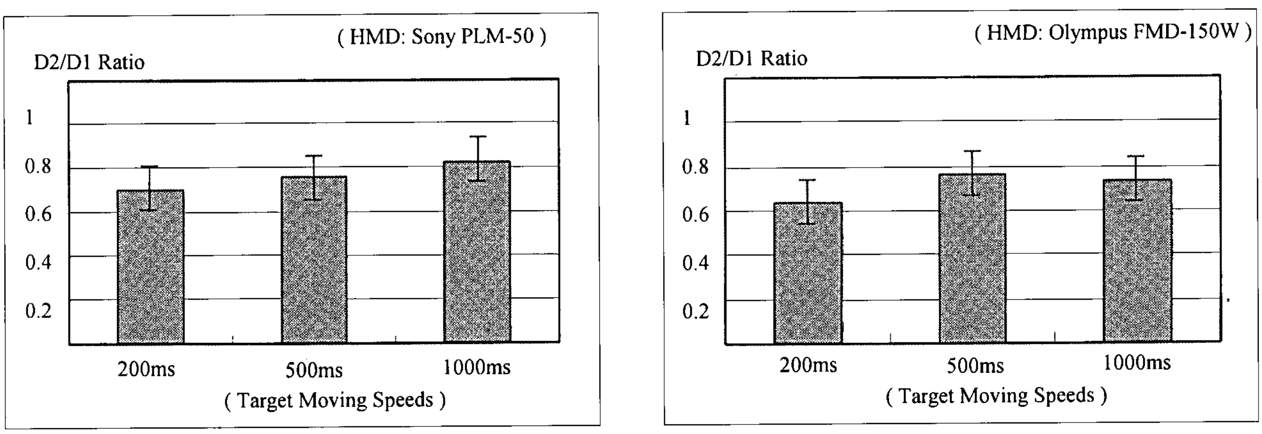
(1) Let a target with a circular form and diameter of 1 cm stay temporarily at the left or right side of the monitor for either one or two seconds.
(2) Each testing time is lasting five minutes. Require the testers to trace the target on display screen, and measure the EOG signals of the visual tracking at the same time.
(3) After a single test, let the tester take a rest for at least 30 minutes (in order to make his visual system recover to a normal state), then repeat the procedure 2 for the another target's moving speed study.

Depending on the combination of three types of display screens and two types of target's moving rhythms, each tester needed to repeat the above testing procedures for six times. And the mean response times at the 1^{st}, 2^{nd}, 3^{rd}, 4^{th}, and 5^{th} minute were determined by averaging ten EOG signals. The



(a) (b)

Figure 4. Results of the response time measured from the EOG signals. Different target moving speeds, i.e. staying the target on screen for (a) one second and (b) two second, both give strong evidences that represent the degree of tiredness for the use of HMD.



(a) (b)

Figure 5. Mean results of the D2/D1 ratio of the user IPD affected by the use of HMD. The ratio value presents the degree of the user IPD trying to match to the system IPD after the use of HMD.

results are shown in figure 4.

For the IPD visual effect study, the target's moving rhythm used in above was modified. The modified testing procedures are:

(1) The target moves among four corners and the center of the display screen (the order of moving is left-superior, left-inferior, center, right-superior, right-inferior) and the moving rhythm is 200ms. (The other two rhythms are 500ms and 1000ms.)

(2) Before the test, measure the user IPD before this test proceeding and use this data to be the basis of normal user IPD.

(3) After the test, measure the user IPD again.

(4) Finish one test, let the tester take a rest for thirty minutes, then repeat the procedure 3.

Each tester needed to repeat the above testing procedures for nine times because of different combinations. The mean values of the IPD effect ratio for each target moving rhythm are shown in figure 5.

In order to realize the physical effects in general of users, and compare the test results with the target tracking model and IPD measurements, we design a questionnaire to examine the degree of visual exhausting situation when the testers watched different monitors and trace the target in different moving rhythms. Table 1 shows the contents of the questionnaire. The mean responses are shown in figure 6.

Table 1. Evaluation form for HMD user.

	No	Comfortable	Mild comfortable	Discomfortable	Severe discomf
Soreness eyes	☐	☐	☐	☐	☐
Fullness eyes	☐	☐	☐	☐	☐
Blurred vision	☐	☐	☐	☐	☐
Out of focus	☐	☐	☐	☐	☐
No distance	☐	☐	☐	☐	☐
Tension headache	☐	☐	☐	☐	☐
Headache	☐	☐	☐	☐	☐
Dizziness	☐	☐	☐	☐	☐
Nausea	☐	☐	☐	☐	☐
Vomiting	☐	☐	☐	☐	☐
Fatigue	☐	☐	☐	☐	☐
Neck stiffness	☐	☐	☐	☐	☐

Others: ______________________________

Name :______________ User IPD:__________

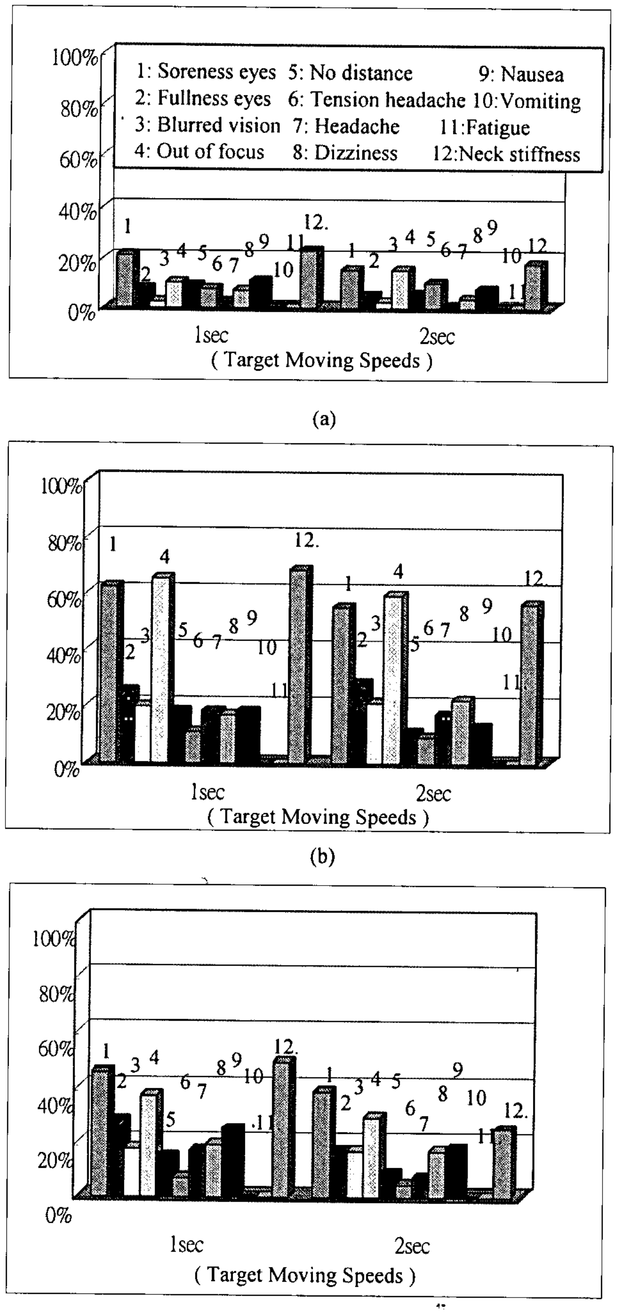


Figure 6. The total responses of the ten testers after watching on the display screen of (a) TV monitor, (b) Sony PLM-50 HMD, and (c) Olympus FMD-150W HMD.

Discussions and Conclusions

In all testes of this study, as long as users keep tracking the target longer than three minutes, the respond time is increased at least twice of that in the initial time. It means that eye muscle may get tired after the tracking test for a long time use. In the measured EOG signals, we also find that more irregular waveforms appeared in the late time than that in the initial time. Most of the irregular EOG signals are clearly correlated to the visual situation of testers with the users' questionnaires.

The tracking respond times of all testers of watching both HMDs are slightly lower than that of watching at TV monitor. The evidence indicates that the testers may sit too close to the TV monitor. During the tracking test, the tester and TV monitor distance was ~45cm that caused significant physical visual tiredness more than the effect from the use of HMD. Based on this point of view, we may say that the HMD system design provides fixed perspective distance which normally has longer distance than the regular user distance siting in front of the TV monitor. The HMD design also provides less eye muscle contraction for keeping trace the motion targets on the display screen.

The results of the EOG respond time also provide another interesting evidence that relates to the motion speed of the target. That is tracking the faster target motion, i.e. the target moved in each 1 second, will obtain better response time than that obtained by tracking the target moved in 2 second. This effect is caused by the testers need to control the eye muscle to stay the visual focal point on the target for the slower target motion longer than that for the faster target motion which usually has less eye muscle contraction than the slower target motion.

For comparing the differences in using two different HMDs, the Olympus has better user responses than the Sony in all studies. This is because the Olympus is a newer product with less total weight and has wider perspective viewing angle. The user responses in the questionnaires also provide the similar information that have less physical effects by the use of Olympus HMD.

In all user IPDs after the use of HMD, their physical visual effects are all exist. It means all the testers have positive effect after tracing the moving target at least five minutes continuously. Results indicated that the user IPD always approach to the system IPD after the use of HMD. We also find that if the user IPD less than the system IPD, for instance, the female users or kids, the physical visual effect may be severer than the opposite situation because the eye muscle need to pay more effort to control the contraction. Although all users IPD can back to the normal situation after the test in some minutes, it is difficult to conclude that the user IPD will not be affected permanently. This effect also needs to be paid more attention on the use of HMD for the kids. In additions, according to the studies, if the user IPD too less than the system IPD, the HMD shall not be used as a long time use equipment. The study of the issue emphasized on the user IPD effect is one of the serious topics about the use of HMD.

In general questionnaire analysis, the effects of the use of HMD always present significant uncomfortable evidences more than that of watching on the TV monitor. Most of the testers after watching the both HMDs have uncomfortable evidences on eyes. Most of the HMD users have neck stiffness evidence that might be caused by the HMD users generally having less body movements during the complete test.

The further studies of this topic shall emphasize on what causes uncomfortable evidences and how serious it will be when the user watches on the screen of HMD continuously. More consistent test results are expected for making solid conclusions on the above issue. The HMD designers shall also pay much more effort on further studies to produce safe and comfortable products in the display device markets.

Acknowledgements

This study was supported by the grants of BV90U15P from Chung-Shan Institute of Science and Technology and NSC 89-2815-C-033-064R-E from the National Science Council, Taiwan, ROC.

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頭配式顯示器對使用者之視覺影響

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收件日期 2001年6月15日；接受日期 2001年8月16日

摘 要

頭配式顯示器(Head Mounted Display, HMD)是一種精巧方便的顯示器系統，它可以用以取代部份已廣泛使用的電視與電腦的CRT螢幕，及使用於筆記型電腦的液晶顯示螢幕。因此，瞭解頭配式顯示器對人體視覺造成的可能生理反應影響，爲本文之主要分析目標。全文內容針對目前於HMD之使用，進行模擬實驗，並且測試在連續長時間配戴使用後，對於人體視覺機能的影響與身體是否呈現不適的感覺等進行分析。爲此，針對使用者眼部肌肉疲勞度與瞳孔間距改變情況，測量各生理參數如眼電圖(EOG)等，與使用頭配式顯示器間對應關係。並且，配合對受測者之視覺疲勞度問卷，以生理學的觀察角度，用以瞭解在頭配式顯示器硬體設計上，對人體機能之影響範圍。根據本研究所量測獲得之資料分析結果，綜合而言，使用頭配式顯示器對人體生理機能之影響，均呈現比CRT較爲負面之現象。除此之外，不同規格之HMD對使用者而言，所呈現的正面、負面生理機能影響，在程度上亦有不同，此研究結果可提供生產設計單位發展頭配式顯示器時之重要參考資料。

關鍵詞：頭配式顯示器、視覺影響、視覺安全分析

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