The influence of desktop light on the comfortable use of computer screen

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Abstract In the evening, a high contrast between a bright computer screen and a dark ambient environment may cause discomfort to the users, especially on their eyes. The objective of this research is to identify the optimal desktop illumination condition for the comfortable use of the computer screen in a dark environment. For this, an experiment was designed where seven illumination conditions were introduced for the users to perform their daily tasks on a computer screen. Fifteen healthy subjects were invited to the experiments. During each session, the blink, the fixation duration and the length of saccade of the eye movements of the user were recorded by an eye tracker, and his/her neck and trunk movements were recorded by a motion tracking system as well. Comfort/discomfort questionnaire, Localized Postural Distribution body map, NASA Task Load Index and the computer user questionnaire were used to subjectively measure the overall comfort/discomfort, the local perceived physical discomfort, the cognitive workload, and general/eye health problems, respectively. Subjective and objective measurement results indicated that users felt more comfort with high intensity warm lights. We also identified that the eye fixation durations and the lengths of saccades, as well as the scores of some questions in the computer user questionnaire, were significantly correlated with comfort/discomfort. It was concluded that the warm (3000K) and high intensity (1500 lux) reduced the visual and cognitive fatigue of the user and therefore improve the comfort of the user during the use of the computer screen.

Keywords: Illumination, comfort, computer screen, eye fatigue

1 Introduction

In an information era, using a computer or laptop is becoming a daily activity of many people. Making the environment more comfortable for using a computer is an important topic in ergonomics. In daytime, the lights in public places, either as the primary or the secondary sources, are more likely to be designed for people to stay alert or enhance their working efficiency[1]. However, in the evening, lights and bright computer screens become the primary light source, and the purposes and content of users using the computer screen are also more diverse compared to daytime. All of these elements post challenges on the design of lights for the use of computer screens in the evening.

Good lighting conditions could improve productivity, while in contrast, inappropriate lighting conditions may cause discomfort, decrease task performance and even result in health problems [2]. Many researchers studied the influence of the quality of light on humans in different condition, for instance, Juslén and Tenner [3] investigated the influence of different lighting environments in workplaces, e.g. factories and offices, on the performance of workers. They conclude that the light intensity and the color temperature of the light may affect human's mood, alertness and may lead to differences in performance. However, extensive literature search did not reveal enough studies about the comfortable illumination conditions for using a computer screen in the dark environment.

The objective of this research is to identify the optimal desktop illumination condition for comfortable use of the computer screen in a dark environment. Our main scientific contributions are: 1) we identified the comfortable illumination condition for using a computer screen in a dark environment, and 2) by correlating different measurement results, we identified the relations between different types measures and the comfort experience, which highlights the possible focus for designing for comfortable use of computer screens.

The remainder of the paper is arranged as follows: In Section 2, we briefly reviewed different aspects of comfort/discomfort and related subjective and objective measures. Section 3 presents the materials and methods of the experiment, and the experiment results are shown in Section 4. Section 5 discusses results from both comfort use and the measurement methods points of view and finally, a short conclusion is drawn in Section 6.

2. Literature review

Comfort and Discomfort

Vink and Hallbeck [4] defined comfort as "*a pleasant state or relaxed feeling of a human being in reaction to its environment*" and they also defined discomfort as "*an unpleasant state of the human body in reaction to its physical environment*". Those definitions indicate that comfort consists of more factors than discomfort, which is mainly caused by the physical interactions. Comfort has many aspects [5] and during the use the computer screen, the feeling of comfort/discomfort can be influenced by multiple factors, e.g., the context, the emotion, the expectations and the content on the screen. Zhang et al. [6] identified the factors that may influence comfort like relaxation, neutral feeling, well-being, energy, environmental and social/psychological factors. On the other side, discomfort is more connected to pain, soreness and numbness, fatigue, environmental factors and anxiety. The effects of those factors are often interrelated, e.g., Hiemstra-Van Mastrigt [7] et al. identified that passengers can be distracted from feeling discomfort by providing food and drinks.

In the long-term use of a computer screen, fatigue can be an important factor influencing a decreased level of comfort and an increased level of discomfort. Fatigue could be induced by physical and physiological causes [8][9] and in the context of using computer screens, it can be categorized to three types: the physical, the visual and the cognitive fatigue. The physical fatigue was defined as "*the reduction in capacity to perform physical work*"[10]. Performing activities that requiring physical efforts may lead to physical fatigue, e.g., maintaining certain postures and moving the mouse for playing a computer game. The World Health Organization (WHO) defined visual fatigue, or visual strain, as a subjective visual disturbance [11]. Visual fatigue often occurs after a long period visual activity, featured by pain around the eyes, blurred vision or headache [11]. Cognitive fatigue and mental fatigue sometimes can be replaced by each other. In behavioral studies, cognitive fatigue can be described as "*the unwillingness of alert, motivated subjects to continue performance of mental work*" [12]. A long duration of cognitive activities will contribute to mental fatigue which results in decrement of cognitive and behavioral performance [13]. The physical, the visual and the cognitive fatigue are not isolated phenomena [14], e.g. little physical exertion is likely to improve the mental performance while heavy physical exertion may reduce it [15].

Measures of comfort/discomfort

A variety of evaluation methods have been used to assess the comfort of users for a better understanding of the ergonomics of different situations. For the overall feeling of comfort/discomfort, 10 point scale comfort/discomfort questionnaires were proven to be effective in many studies [16][17]. Regarding the measurement methods of different factors which contribute to comfort/discomfort, they can be categorized in four types: subjective measures, performance measures, psychophysiological measures and analytical measures [18]. In the context of reading a computer screen in the dark environment, subjective measures and psychophysiological measures can be addressed as for many tasks, there is no clear task objective.

Subjective measures are designed to collect the opinions from the operators about the workload/human effort, satisfaction, preference, user-experience, etc. In spite of the criticism on the validity and vulnerability to personal bias of those self-reporting methods, subjective measures with the low cost and ease of administration, as well as adaptability, have demonstrated their advantages in a variety of domains, including healthcare, aviation, driving, etc. The LPD body map [19] is a widely used instrument in many applications for subjectively evaluating the physical discomfort of different parts of the body. For visual fatigue, there are questionnaires about user's feeling after using a computer screen including visual fatigue, e.g., the 10-item questionnaire about symptoms of vision [20], the Computer User Questionnaire (CUQ) [21], Computer Vision Syndrome Questionnaire (CVS-Q) [22]. Subjective measures can also be studies by indirect methods in the measurement of cognitive load where the NASA-Task Load Index (NASA-TLX)[23] is an typical example. It was designed to measure the perceived workload of the subject within six dimensions: Mental demand, physical demand, effort, performance, temporal demand, and frustration, and has demonstrated a high reliability and sensitivity in many studies [24].

Psychophysiological measures are physiological measures used to index psychological constructs [25]. For instance, Goldberg and Kotval [26] were among the pioneers of investigating the usage of eye tracking measures when browsing different types of web-pages. In this research, we broaden psychophysiological measures to objective measures [27] as physical activities are important indicators of comfort/discomfort, e.g., Brachynskyi [28] evaluated the comfort of sitting postures while using touch displays by 1) a motion capture system and 2) a custom built chair which measured the forced applied by the user in various directions. For visual fatigue, there are studies that evaluated visual comfort/fatigue [29] using eye tracking devices based on the length of saccades, the fixation durations, and features related to blinking, etc. In the evaluation of cognitive workload/fatigue, Shriram [30] discovered that electroencephalography (EEG) measures were useful in finding and evaluating the relative contributions of workload that are not detected by other indexes.

In summary, many subjective and objective measures have been applied to identify different issues and proposed design suggestions regarding comfort/discomfort, and outcomes of those measures are often interrelated [27]. However, selecting the proper measures and combining the outcomes of those measures for choosing proper illumination conditions for comfortable use of computer screens are still challenging questions.

3. Materials & Methods

Materials:

For identifying an optimal illumination condition for the comfortable use of computer screen in a dark environment, an experiment was designed with different illumination conditions. The experiment was carried in a dark room where the (natural) light was shielded by curtains. The light sources are restricted to the screen of laptop and the light of a desktop lamp. During the experiment, only a researcher and the participants stayed in the room where the researcher gave instructions and adjusted light conditions following the protocol. The height of the desk is 720 mm, which was the height that participants were used to. The humidity and temperature of the room were kept same throughout the experiment. The light intensity of the laptop screen was set at 400 cd/m^2 and the angle of the screen was adjusted perpendicular to the eyesight of the user. The desktop lamp was adjusted to such an angle that for the participants, there was no direct viewing of the light source. The color temperature and the light intensity of the desktop lamp were adjustable, resulting in 7 possible conditions (Table 1).

Table 1. 7 conditions of the illumination conditions

	Condition 1	*Condition 2*	*Condition 3*	*Condition 4*	*Condition 5*	*Condition 6*	*Condition 7*
Color temperature (K)	N/A	5000 K	3000 K	5000 K	3000 K	5000 K	3000 K
Light Intensity (Lux)	0 (Off)	1500 lux	1500 lux	375 lux	375 lux	675 lux	675 lux

Participants:

Fifteen healthy subjects (mean age = 23±3.2) were invited to the experiments. Among them, 6 were males and 9 were females. All participants' dominant hand was the right hand and their native language was Chinese, and they met the following criteria: 1) in good health condition (without mental or physical disorder); 2) with normal visual acuity (with or without vision correction equipment); 3) experienced with using laptops; 4) had enough rest before the experiments; 5) were able to read and comprehend Chinese and English text.

Evaluation measures

a. Objective measure of the process

Three objective measures were used to measure the use of the computer screen in a dark environment. The ProMove® MINI [31], which is a body movement tracking device, was used to record the movements (rotation) of the neck and the trunk of users during the experiments. The average fixation time, the average length of saccade and the blinking times of eyes were measured a Tobii® X2-30 eye tracker[32]. A camera was deployed next to the user to record the experiment scenario as well as the postures of the participants.

b. Subjective measure of the process

In the experiment, each participant was asked to complete a set of questionnaires using the same computer. Among those questionnaires, the Comfort/Discomfort questionnaire [16] was used to evaluated the overall feeling of users regarding their comfort/discomfort experience. The LPD body map [33] allowed users to point out the discomfort part of their body. The NASA-TLX [24] was used for assessing mental workload on the use of the computer screen. The users were also able to report general and eye health problems by the CUQ [21]. A laptop was used for performing reading tasks and filling in questionnaires electronically utilizing the Ergo-LAB3.0 platform. Figure 1 presents the setup of the experiment.

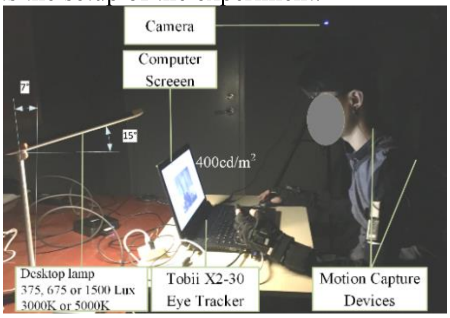


Fig.1. Setup of the experiment

Protocols

A pilot test was conducted to verify the setups and guarantee that all materials had a similar cognitive complexity, the colour saturation and the brilliance. Prior to the experiment, the informed consent was acquired from the participant participating in this study. The participant was then asked to adapt himself/herself to the lighting environment for 5 minutes. Meanwhile, with the help of the researcher(s), he/she wore the motion capture modules. Each experiment consisted of 7 sessions in a randomized sequence, corresponding to the 7 illumination conditions (Table 1), respectively.

Before the first session, the researcher(s) introduced the content of the experiment and the procedure. The contents of the 7 sessions were similar, each had 4 reading/watching tasks. The first one was reading a recent news in Chinese, covering the fields of science and technology, health/medicine, or culture/history. All chosen news was recent news, they had similar length (~4000 Chinese characters), amount of illustrations and difficulty, which was evaluated by the researchers in the pilot. In the reading task, each page of the news was played for 20 seconds, then the next page was displayed automatically. In total it costed approx. 3 minutes to display every page of the news automatically. Then the respondents were asked to fill the first NASA TLX.

The second task was to read comics. The comics are excerpted from *Peanuts* by Charlie Schutz (10 pages). Each page included one comic strip and it was played for 10 seconds (in total 100 sec. for 10 pages). In the third task, the participants were asked to read a piece of scientific article in English, which has 300 words and displayed in 3 pages. Similar to Task 1, those (pieces of) scientific articles were selected by the researchers to guarantee that the participants were familiar with the topics and the length and the difficulties were similar. After this task the participants were asked to finish the second NASA TLX questionnaire. The last task was to watch a part of the BBC documentary movie "*The Planet*" for 3 minutes. After finishing this task, participants were asked to finish two questionnaires: the comfort/discomfort questionnaire and the CUQ.

After finishing a session, the participant was given 10 minutes to take a rest while the researchers were changing the illumination condition and finishing administrative tasks. Eyewash was made available for the participant to prevent serious eye fatigue during the experiment.

Data processing methods

All collected subjective data were preprocessed before analysis. Using the minmax scaler [34], we normalized data in the same category to a range from 0 and 1 regarding each subject, i.e., for a score on the level of comfort, 0 is the minimal and 1 is the maximal level of comfort. The Student t-test was used to identify the statistically significance between two sets of data and the Pearson correlation coefficient was used to determine the linear correlation between them. Linear regression is used to model the relations between predictors and a criterion variable, e.g., the level of comfort. In data visualization, the violin plot, which is combination of box-plot and kernel density estimate[35], was introduced to present the statistical distribution of the acquired data.

4. Experiment results

The results of comfort/discomfort questionnaire indicated the overall comfort/discomfort feelings of the participants for each condition. In Fig.2, the violin plot of comfort/discomfort of the users regarding the 7 conditions is presented where the scores were normalized to a value between 0 and 1. Regarding comfort, it was found that Condition 2 (mean = 0.61±0.32), Condition 3 (mean = 0.71±0.32), Condition 5 (mean = 0.68±0.26) and Condition 7 (mean = 0.65±0.29) scored higher, and they were statistically significantly better (p=0.001, 0.009, 0.004 and 0.007, respectively) compared to Condition 1 (pure dark environment, mean = 0.28±0.31). For discomfort, similar results were observed where Condition 2 (mean = 0.37±0.34), Condition 3 (mean = 0.22±0.30), Condition 5 (mean = 0.24±0.28) and Condition 7 (mean = 0.24±0.25) were statistically significantly better than Condition1 (mean = 0.82±0.29).

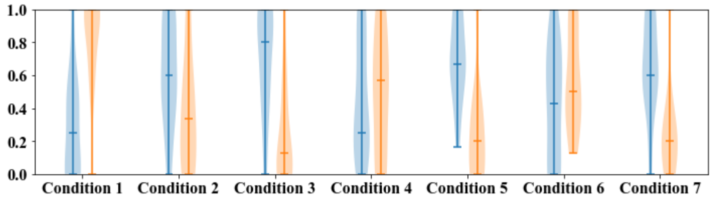


Figure 2: Comfort (Blue) and Discomfort (Orange) of participants in 7 conditions, for comfort, the vertical axis stands for the level of comfort (1 = high comfort), for discomfort, the vertical axis stands for the level of discomfort (1 = high discomfort)

Figure 3 presents the normalized mean score of the LPD body map regarding 7 conditions. It can be found that participants experienced similar discomfort regarding 7 conditions. Nearly all users reported discomfort in the buttock (O, P), the hip (C, V), the neck (S) and the shoulder (T, Y). Though Condition 1 and Condition 2 performed slightly better regarding the neck, and the shoulder, while these were not statistically significant.

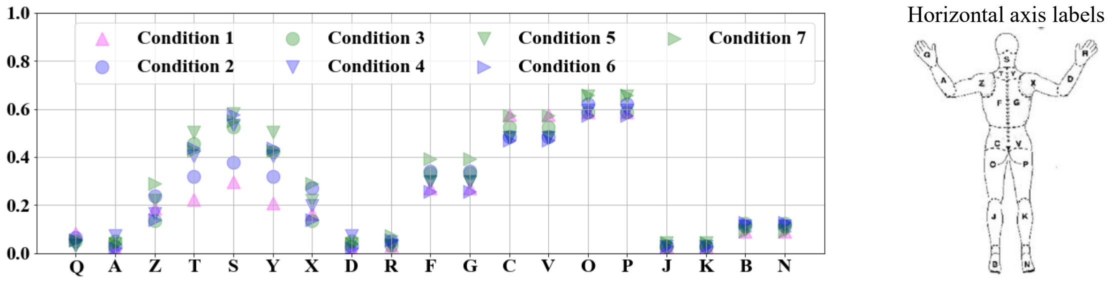
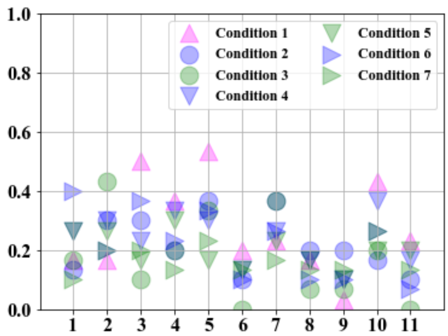


Figure 3: The normalized results of the LPD questionnaire regarding each illumination condition (right: the correspond part of each letter regarding the body, vertical axis: level of discomfort and 1 = high discomfort)

The normalized results of CUQ (Fig.4) indicated the users' subjective feeling regarding different aspects of using the computer screen in the 7 conditions, especially on their eyes. Based on the figure, it can be found that Condition 1 gave the users the most negative feelings except for question *2 (Overall bodily fatigue or tiredness)* and 9 *(Letters on the screen run together)*. And regarding question *3 (Burning eyes)* and *6 (Squinting helps when looking at the computer)*, Condition 3 was statistically significantly better than Condition 1 ($p \leq 0.05$). The users appreciated Condition 3, 4 and 5 more than Condition 2, 4 and 6, which can be observed that the green markers are lower than purple markers in nearly all answers.



Horizontal axis:
1.Headaches during or after working at the computer;
2.Overall bodily fatigue or tiredness;
3.Burning eyes;
4.Distance vision is blurry when looking up from the computer;
5.Dry, tired, or sore eyes;
6.Squinting helps when looking at the computer;
7.Neck, shoulder, or back pain;
8.Double vision;
9.Letters on the screen run together;
10.Driving/night vision is worse after computer use;
11."Halos" appear around objects on the screen

Fig.4. The normalized mean results of the computer vision questionnaire (Vertical axis: Normalized scores of CUQ, 1 = high discomfort)

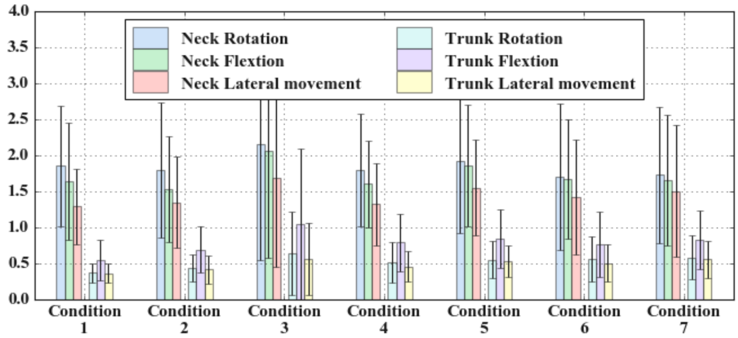
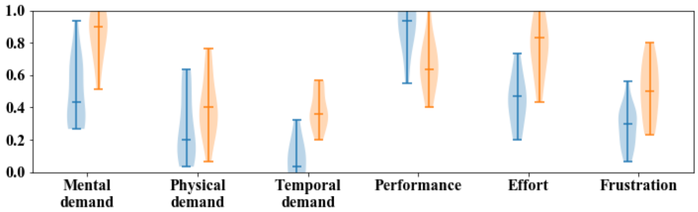
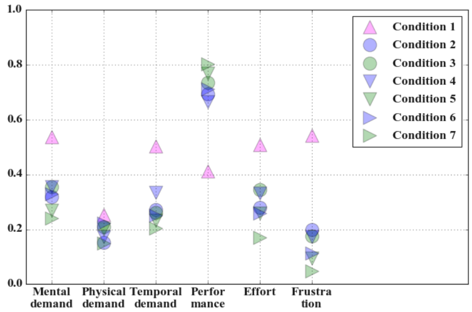


Fig.5. Mean movement speed of the user (Vertical axis unit: degree/second)

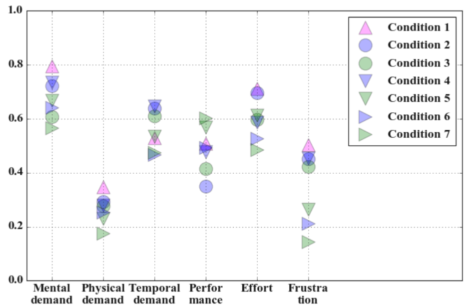
Figure 5 presents the mean movement speed (in degree/second) of the neck and the trunk of the users during the experiments regarding 7 conditions, respectively. The users moved their neck much more than the trunk. Regarding different conditions, users moved slightly more in Condition 3, followed by Condition 5. However, the differences were not statistically significant.



(a) NASA TLX results of Task News (blue) and Task Article (yellow)



(b) Result of NASA TLX regarding reading task 1



(b) Result of NASA TLX regarding reading task 2

Fig.6. Normalized results of the NASA TLX questionaires (vertical axis: 0 = lowest and 1 = lighest regarding the question)

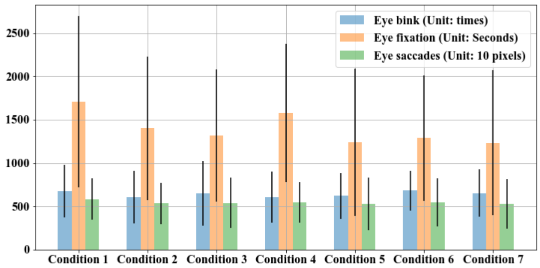


Fig.7: Results of eye movements (Verical axis units are illustrated in the legend)

Two reading tasks were conducted by participants in the experiment, one was reading a Chinese (native language) news (*Task News*) and another is reading (part of) an English (secondary language) article (*Task Article*). For all participants, the cognitive workloads were different and it can be reflected in the violin plot of NASA TLX regarding two tasks (Fig.6a). In the figure, it can be observed that participants agreed that *Task News* had less mental demand, had less physical demand, they read it faster, performed better, spent less effort and had less frustration. Regarding the cognitive workloads in 7 different conditions, participants rated *Task News* and *Task Article* differently as Fig.6(b) and (c), respectively. Generally, for *Task News*, all participants rated that Condition 2, 3, 4, 5, 6 and 7 better than Condition 1 and except the physical demand, those differences were statistically significant. Among Condition 2 to 7, Condition 3, 5 and 7 (green markers) were slight less demanding than Condition 2, 4 and 6. For *Task Article*, there was no statistically significant difference among all conditions. Condition 3, 5 and 7 (green markers) were slight less demanding regarding mental demand and physical demand, and participants considered they performed slight better and had less frustration. Eye tracking data (Fig.7) also indicated that during the experiment, participants had similar eye blink times and length of saccades, but in Condition 3, 5 and 7, participants had less eye fixation durations.

5. Discussions

In the process of reading the laptop screen under different illumination conditions, three types of fatigues, namely visual fatigue, cognitive fatigue and body fatigue, may have influenced the comfort of the user. In the design of the experiment, regarding the body fatigue, we utilized the LPD body map to detect subjective feelings of discomfort and motion sensors to detect the movements of the body. Visual fatigue and cognitive fatigue can be difficult to separate in terms of human perception. We utilized the CUQ to detect the subjective feeling of visual fatigue, and eye tracking was used to detect the activities of eyes. In the cognitive side, the NASA TLX was used to subjectively evaluate the cognitive demand of the tasks. Finally, the comfort/discomfort questionnaire was used to acquire the overall comfort feeling of the participants in the process.

General comfort vs illumination conditions

Fifteen participants experienced using computer screen in 7 different illumination conditions. Regarding general comfort, Condition 1 (dark environment) was the least preferred choice of the participants. In the rest conditions, Condition 3, 5 and 7 performed (slightly) better than Condition 2, 4 and 6. By grouping all conditions according to the color temperature and the light intensity, Fig.8 presents the levels of comfort and discomfort of these two groups, respectively. The participants preferred the warm light (3000K) more than cold light (5000K) as the left in Fig.8 (statistically significant: comfort: p=0.004; discomfort, p=0.001). For the light intensity, participants preferred strong light (1500 lux, Condition 2 and 3) more than the medium (675 lux, Condition 6 and 7) and low light (375 lux, Condition 4 and 5) conditions as the right of Fig.8.

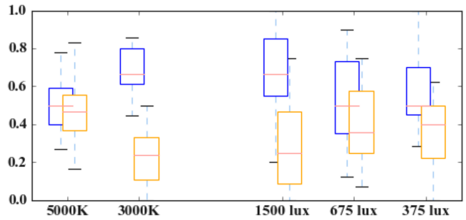


Fig.8: Comfort (blue) /discomfort (orange) regarding color temperature and light intensity (for comfort, the vertical axis stands for the level of comfort (1=high comfort), for discomfort, the vertical axis stands for the level of discomfort (1=high discomfort)

Body fatigue vs illumination conditions

In the experiment, the ergonomics setups of the chair, the table and the computer were fixed. Therefore, the LPD body map did not show significant differences of discomfort for different parts of the body among different conditions. However, in the shoulder, the back, the hip and the buttock, participants reported in Condition 1 (dark environment) was less discomfort. This interesting phenomenon will be explained in the following section *Relations of measures*. Regarding the physical movements of the body, we found that the average rotation speed of the head was three times more than the trunk in reading task. However, we did not find significant difference regarding different illumination conditions.

Visual and Cognitive fatigue vs illumination conditions

Illumination condition is more likely to directly affect visual fatigue while cognitive fatigue has more correspondence with the content of reading material (the language, the difficulty and the fields it covered). In the experiments, *Task News* and *Task Article* had different cognitive workloads, where the latter was heavier. Users reported differences on these two types of cognitive workloads regarding the 7 conditions. For the *Task News*, all participants reported that in Condition 1, the mental and temporal demands were higher. It took more effort, they performed less good and had more frustration. However, this effect was not observed in the *Task Article*. In this task, participants fully concentrated on the content of the task and they were not fully aware of the influence of the illumination conditions.

Besides the problems with CUQ question *3. Burning eyes and 5. Squinting helps when looking at the computer* in Condition 1, where no illumination was provided, the color temperature of light also influences the visual and cognitive fatigue of the participants. In Condition 3, 5 and 7 (warm light), participants had less eye fixation durations than other conditions, which indicated that warm light helped the user finishing the cognitive process in shorter time. This can also be reflected in the scores of the NASA TLX regarding both tasks, where the green markers are slight lower in mental demand, efforts and frustration, and slightly higher in performance.

Relations of measures

Condition 1 (dark environment) was the least comfortable among all conditions, however, in the LPD body map, participants reported that Condition 1 was better regarding discomfort in the shoulder, the back, the hip and the buttock. Meanwhile in the CUQ, participants reported that they encountered problems with *Burning eyes and Squinting helps when looking at the computer* in Condition 1. This phenomenon can be explain by that "*Pain will emerge over other demands for attention*" [36]. The participants reported less discomfort as they experienced more problems with their eyes. This finding is in accordance with the literature [37] where passengers felt less discomfort when food and drinks were provided.

Parts of the results of CUQ were correlated with the results of the comfort/discomfort questionnaire. Scores of Question *3.Burning eyes* and *10.Driving/night vision is worse after computer use* had statistically significant negative correlations with the values of comfort, scores of *3.Burning eyes, 5.Dry, tired, or sore eyes;* and *10.Driving/night vision is worse after computer use*, had statistical significant positive correlations with discomfort. Details of the correlations are presented in Table 2.

Table 2: Correlations between scores of CUQ and the values of comfort/discomfort (*P≤0.05)

CUQ	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*
Comfort	-0.33	0.623	-.904*	-0.665	-0.740	-0.647	0.239	-0.209	0.457	-0.856*	-0.469
Discomfort	0.289	-0.588	0.937*	0.662	0.813*	0.614	-0.144	0.222	-0.449	.800*	0.442

Using the linear regression method, we modelled the relationships between the comfort/discomfort and the scores of CUQ. In the regression, the scores of Questions 3, 5 and 10 (P≤0.05) were used as predictors, and scores of comfort and discomfort were used as criterion variables. Eq.1 presents the model where the coefficients in column 1 to 3 are associated with CUQ question *3. Burning eyes*, 5. *Dry, tired, or sore eyes* and *10. Driving/night vision is worse after computer use*, respectively. Column 4 is the constant of the model. Based on the values of the coefficient, it can be found that Question 3 in the CUQ has the largest influence on the level of both comfort and discomfort, followed by Question 10 and Question 5, which indicates that burning eyes is the major reason of the lower level of comfort levels and higher level of discomfort levels, respectively. It is worth mentioning that the absolute values of coefficients regarding discomfort are higher than that of the comfort, which is in accordance with the conclusion made by Vink and Hallbeck [4] that the causes of discomfort are mainly physical factors where for comfort, the causes can be more complicated.

$$\begin{bmatrix} Comfort \\ Discomfort \end{bmatrix} = \begin{bmatrix} -0.711 & -0.013 & -0.776 & 0.949 \\ 1.001 & 0.298 & 0.736 & -0.141 \end{bmatrix} \begin{bmatrix} 3.\,Burning\ eyes \\ 5.\,Dry, tired, or\ sore\ eyes \\ 10.\,Vision\ is\ worse \\ 1 \end{bmatrix} \quad 1$$

Subjective and objective measures

Subjective and objective measures were used in the experiment to measure different types of fatigue influenced by various elements. For instance, we measured the cognitive process using eye tracking and NASA TLX, and the overall process was measured by comfort/discomfort questionnaires. In Table 3, the correlations between the eye fixation durations and the length of saccades, and the comfort/discomfort are presented. It shows that the longer the fixation durations are, the lower the comfort is. A similar phenomenon was identified in the length of the saccades. Therefore, conditions in which fixation durations and lengths of saccades were shorter, the comfort improves and discomfort reduces.

Table 3: Correlations between eye fixation, saccade and the values of Comfort/discomfort (*P≤0.05)

	Eye fixation durations	*Length of Saccades*
Comfort	-0.783*	-0.849*
Discomfort	0.794*	0.891*

Eye fixations and saccades were also correlated to the scores in the NASA TLX. Table 4 lists the Pearson correlation coefficients between them. Eye fixation durations were correlated (P≤0.05) to Mental demand, Physical Demand and Frustration. Regarding the length of saccades, it was correlated (P≤0.05) to Physical Demand, which reflected the physical movements of eyes in the reading process.

Table 4: Correlations between eye fixation, saccade and the values of NASA TLX (*P≤0.05)

	Mental demand	*Physical demand*	*Temporal demand*	*Performance*	*Efforts*	*Frustration*
Eye fixation	0.880*	0.830*	0.374	-0.240	0.641	0.802*
Saccade	0.715	0.827*	-0.006	-0.107	0.566	0.625

Limitations

In this study, we investigated the comfort experience using a computer screen in a dark environment. For simulating the use of computers in the leisure time (evening), the designed tasks were easy and without a clear objective, tests [38] were not arranged as well. Considering that the real reading condition can be more complicated, there are more factors to be investigated in a natural environment, e.g., colors of the environment, ergonomics of the chair and the table, ambient noises. Besides, in order to prevent eye fatigues of participants, we limited our experiments to 7 discontinuous sessions, which may also influence the comfort/discomfort of the users. Additionally, it is known that with longer durations comfort reduces further and discomfort increase [39], but it is also known that humans move more when they are longer in one position [40]. This means that it is hard to extrapolate these results under laboratory conditions to natural environments and further research is needed on how this can be translated to daily life. On the other hand, it is clear that there are preferred conditions like warm light and not completely dark, which are easy to implement in daily life.

6. Conclusion:

Using subjective and objective measures, the overall comfort/discomfort of the users in 7 different lighting conditions was recorded as well as three types of fatigues: the body fatigue, the visual fatigue as well as the cognitive fatigue. The results indicated that the strong warm light (1500 lux, 3000K) illumination condition reduced the visual fatigue and the cognitive workload of the users, and it is correlated to the improved the comfort of the user. Regarding the measures, we identified that the eye fixation durations and the lengths of saccades, as well as the scores of some questions in the computer user questionnaire, were significantly correlated with comfort/discomfort, which cast a new lens on the comfort/discomfort experience of the users.

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