INFLUENCE OF VIEWING DISTANCE AND SIZE OF TV ON VISUAL FATIGUE AND FEELING OF INVOLVEMENT

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ABSTRACT

Using physiological and psychological measurements, we carried out experiments to investigate the influence of viewing distance and TV screen size on visual fatigue and feeling of involvement using 17-inch, 42-inch and 65-inch displays. The experiment was an ordinary viewing test with the content similar to everyday TV programs for one hour including scenery, sport, drama, etc., with commercials sandwiched in between. The number of participants was 16 (8 persons aged 21-31, and 8 persons aged 50-70) for each display size. In all, 48 participants viewed 3 display sizes. In our physiological evaluation, CFF (critical flicker fusion frequency), blink rate and a sympathetic nerve activity index were used; and in the psychological evaluation, questionnaires and interviews were employed. Our results, based on physiological and psychological measurements, suggest the optimum viewing distance to be around 165-220 cm, irrespective of screen size. Our evaluations, which are based on optimum viewing distance for minimal visual fatigue and a closer feeling of involvement, might therefore not agree with the currently recommended viewing distance, which is defined as 2 or 3 times the display’s height.

Keywords: visual fatigue; viewing distance; TV; ergonomics; home environment; physiological and psychological measurements

INTRODUCTION

Technological progress and shifting lifestyles have led to significant changes in the everyday TV viewing environment. On the technical side, the replacement of CRT (cathode ray tube) TVs with widescreen PDPs (plasma display panels) and LCDs (liquid crystal displays) has progressed rapidly. Bigger screens and longer TV viewing times due to changing TV viewing styles, which are becoming more diverse due to the broadening content, such as video games and web pages in addition to conventional TV programs, make it increasingly necessary to consider the effects of these changes on visual fatigue and health. To develop TVs that keep visual fatigue to a minimum and to be able to propose optimum TV viewing conditions, these factors need to be investigated in addition to the conventional focus on image quality and presence.

Numerous studies have been carried out, particularly in the field of ergonomics, on visual fatigue experienced during VDT work, (Takahashi, 1993; Mitsuhashi, 1994; Takahashi, 1999; Sakamoto et al., 1998; Kaneko et al., 2000; Nakamura et al., 1991; Hoshino et al., 1991; Osaka, 1985; Wang et al., 2003; Wang et al., 2000; Oetjen et al., 2009).

However, conventional VDT work chiefly comprises text-inputting tasks. Still images are typically used in TV viewing tests for exploring the optimum viewing distance, although conventional TV viewing comprises mainly video materials and animations. For these reasons, more studies need to be carried out on the visual fatigue caused by viewing video and animations to find out if the evaluation index and the recommended distance obtained in prior studies can be adapted to fit the new technologies and viewing

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styles. Moreover, to evaluate the overall mental and physical workloads caused by the task load, we used measurements of subjective responses (accommodation relating symptoms and pain-like symptoms) (Takahashi, 1993) and physiological responses (CFF, balance of autonomic nerve activity) (Osaka, 1985).

On the other hand, with regard to viewing distance, the recommended distance for high definition TVs is currently 2 or 3 times the display’s height (Narita et al., 2001; ITU-R, 1998; ITU-R, 1997). In these experiments to explore the optimum viewing distance, the display area and display luminance were set at constant values. The simulation images, each of which had a different number of equivalence scanning lines, were presented to each participant in random order. Participants selected the viewing distance at which the image was least affected by the scanning line structure, and looked the clearest; and this viewing distance was treated as the optimum viewing distance (Ohtani et al., 1976). The recommended value of the optimum viewing distance was obtained by making the viewer less aware of individual pixels; thus the evaluation methods were based on subjective evaluations, not on objective gauges such as physiological measurements (ITU-R, 1998; ITU-R, 1997). It has not yet been verified whether the relative viewing distance (H: calculated viewing distance using display height (H)) can be adapted to an optimum viewing distance to ensure less visual fatigue and a closer feeling of involvement, which may or may not be affected by other mental factors.

In the authors’ first report (Sakamoto et al., 2010), we explored how to measure visual fatigue objectively and obtain information on optimum viewing distance. The authors’ investigation employed both physiological and the psychological data using a 42-inch PDP display. The results showed that visual fatigue reached a minimum at a distance of 3 to 4 times the height of the display (3-4H: 165-220 cm); this viewing distance was very close to the conventionally-advertised optimum viewing distance (ITU-R, 1998; ITU-R, 1997). If we could get the same results for optimum viewing distance using another display size, our evaluations would agree with currently recommended relative viewing distances (ITU-R, 1998; ITU-R, 1997). However, in the pilot experiment using a 20-inch display, our results, based on physiological and psychological indices, indicated the optimum viewing distance to be around 165 cm (7.9H). This viewing distance differs markedly from the conventional optimum viewing distance (3H; 63 cm). Therefore, in some ranges of display size, it appears that the optimum viewing distance might be around 165-220 cm, an absolute value regardless of display size; alternatively, there might not be a fixed relationship for any display size.

In this study, our second report, we made objective measurements of visual fatigue and obtained information on optimum viewing distance. Our investigation employed both physiological and the psychological data using 17-inch, 42-inch and 65-inch displays and at fixed viewing distances (110, 165, 220 and 330 cm), regardless of display size. In our physiological evaluation, CFF (critical flicker fusion frequency), blink rate and a sympathetic nerve activity index were used; and in the psychological evaluation, questionnaires and interviews were employed.

METHODS

The experiment was an ordinary viewing test with content similar to everyday TV programs. The program comprised scenery, sport, drama, etc., with commercials sandwiched in between. To prevent sleepiness, an on-screen text-based task (a telop task) was included for 1 minute after each commercial. The task was to count the number of strokes in part of one of a string of 26 Japanese kanji characters, each taking three seconds to pass from right to left of the screen (Fig. 1). For example, for the 42-inch display size, as the width of the screen is 93 cm, the text velocity was 31 cm per second. On-screen text was continuously displayed for 1 minute. The background color was grey (IRE = 90%). The text color was black (IRE = 0%). To eliminate the effect of boredom caused by watching the same program several times, four different programs were prepared, with the same structure and pattern but with different scenes.

Participants

The number of participants was 16 for each display size. In all, the total number of participants was
48 persons. To examine the difference between generations, two generation groups were selected. The number of one group was 8 persons aged 21–31 for each display size, and the number of the other group was 8 persons aged 50–70 for each display size. Any visual acuity under 0.8 was corrected using contact lenses or glasses. Each participant also took part in experiments in four conditions (controlling viewing distances) using only one display size. Each participant gave his or her written informed consent to take part in this experiment according to the protocol approved by the Osaka City University Research Ethics Committee at the Graduate School of Human Life Sciences.

**Apparatus**

The following 17-inch LCD TV and 42-inch and 65-inch plasma TVs (PDPs) were used. 17-inch LCD TV (Panasonic TH-17LX8; resolution: HD 1368 x 768, aspect ratio: 16:9, width: 462 mm, height: 340 mm, depth: 176 mm), a 42-inch Plasma TV (PDP) (Panasonic TH-42PX600; resolution: HD 1368 x 768, aspect ratio: 16:9, width: 920 mm, height: 518 mm (physical height: 535 mm), contrast ratio: 4,000:1 (Maximum ratio: 10,000:1)), and a 65-inch plasma TV (PDP) (Panasonic TH-65PX500; resolution: HD 1368 x 768, aspect ratio: 16:9, width: 1754 mm, height: 985 mm).

**Items measured**

The following items, confirmed by prior studies to yield effective results (Okada *et al*., 2007; Okada *et al*., 2005; Sakamoto *et al*., 2007) were adopted. 1) Subjective assessment of fatigue (SAF) by questionnaires and interviews, 2) blinking rate, 3) electrocardiogram and 4) CFF. Blinking rates were calculated by monitoring an electrooculogram (vertical EOG). The level of sympathetic nerve activity (LF/HF) was calculated by monitoring an electrocardiogram (ECG). LF/HF was defined by the ratio of the low frequency band (LF: 0.04 - 0.15 Hz) and the high frequency band (HF: 0.15 - 0.5 Hz), calculated by employing FFT analysis using the R-R interval based on heart rate variability obtained from an electrocardiogram (Ishibashi *et al*., 2007; Ishibashi *et al*., 1999). Task performance (rate of correct answers) for on-screen text tasks was also calculated. Subjective assessment of fatigue (SAF-J: work-related fatigue feelings, *jikakushō shirabe* (in Japanese)) provided by the Japan Society for Occupational Health (Sakai, 2002) and SAF-M (eye fatigue items: *Me no Hirōdo Chōsa* (in Japanese)) (Takahashi, 1999) was performed before and after the test. Interviews (Table 1) were performed after the test.

In addition, SAF-J comprised Group 1 (Sleepy feelings), Group 2 (Erratic feelings), Group 3 (Nausea and headache), Group 4 (Increasingly tired feelings) and Group 5 (Eye fatigue feelings).

In this study, Group 5 (Eye fatigue feelings) was adopted as the index of SAF-J for visual fatigue measurement. Group 5 comprised eye irritation, eye fatigue, pain in the eyes and dry eye, etc., the items related to visual fatigue.

SAF-M comprised the items of sleepiness, fast blinking, eye irritation, pressure on the eye and pain in the eye. It appeared sufficient for psychological measurements to evaluate visual fatigue directly using only SAF-M. However, the objective of this study was to obtain the optimum viewing distance that resulted
in the least visual fatigue and closest feeling of involvement when watching a widescreen TV. Because SAF-J also comprised erratic feelings (irritation, anxiety, etc.: related to sympathetic nerve activity) and disagreeable feelings (headache and nausea, etc., related to motion sickness), two psychological measurements (SAF-M and SAF-J) were adopted. After each viewing test, an interview was held (Table 1), and after four conditions of viewing test (110, 165, 220, 330 cm), evaluation of TV watching was carried out, which included the items for the less mental fatigue evaluation score, feeling of involvement score and total evaluation score. In addition, items for less mental fatigue and for feeling of involvement were asked only to the participants of the 20s - 30s (24 persons): after experiments with the participants of the 50s - 70s, we felt it would be better to add these items to the evaluation.

**Viewing distance**

The viewing distance had the following four levels: 1) 110 cm, 2) 165 cm, 3) 220 cm, and 4) 330 cm. The viewing distances were defined by the screen-to-eye distance based on the height (H) of the 42-inch screen (the display height for a 42-inch TV is about 55 cm). In the pilot experiments, some participants had claimed that a viewing distance of 80 cm (1.5H) was too close for comfort. Some participants also reported that the optimum viewing distance should be greater than 2H, since awareness of individual pixels increased visual fatigue (Narita et al., 2001). The minimum viewing distance was therefore set at 110 cm (2H). The average Japanese living room is small, making viewing distances greater than 330 cm impractical. The maximum viewing distance was therefore set at 330 cm (6H) (Fig. 2). Because the pilot experiments suggested the influence of both the relative distance and the absolute distance, the viewing distances were set to the absolute viewing distances of 110, 165, 220 and 330 cm without using relative viewing distances (2H, 3H, 4H and 6H).

**Experimental setup**

Test room conditions were maintained at constant levels: ambient temperature of 23 °C, relative humidity of 50%, and illumination of 150 lx. Humidity, which affects blinking rates, was strictly controlled. Illumination was set at 150 lx to simulate the average light level of a Japanese living room based on JIS standardization.

**Procedures**

Participants sat in a chair that held their viewing distance at 110, 165, 220 and 330 cm. At 110, 165,
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22 and 330 cm, 3 minutes’ rest was imposed before, between and after two 30-minute video films (the test time totaled 60 minutes) (Fig. 3). CFF measurements and SAF were performed before and after the test, and EOG and ECG were monitored continuously during the test and before and after the test. To eliminate the order effect, the order of viewing distances (110, 165, 220 and 330 cm), which was controlled in the test, was varied for each participant. The tests were performed under the first two sets of conditions on two consecutive days, and under the two remaining sets of conditions on two consecutive days one week later. (It took four days in all for each person to perform the tests under the four sets of conditions).

Statistical analysis
It was difficult for one participant to perform the tests for three display types considering testing time, work load and boredom caused by watching the same program several times a participant. For this reason, two-way ANOVA without replication among viewing distances and among participants was performed for subjective assessment (SAF-J and SAF-M) and physiological evaluation (blinking rates, heart rate variability (LF/HF), CFF) and task performance as measured by the number of correct answers. In addition, a post hoc test (Tukey-Kramer test) was performed to identify any significant differences between the indices among these distances. Moreover Friedman test among viewing distances and among participants was performed for the total evaluation item, feeling involvement item and less mental fatigue item for SAF. As
the scoring for these three items were different from SAF-J or SAF-M, Friedman test was adopted. In addition, a post hoc test (Bonferroni test) was performed to identify any significant differences between the indices among these distances. The level of significance was set at \( p = 0.05 \).

RESULTS

Experiment
Subjective assessment of fatigue (SAF)

The SAF-J results of Group 5 (eye fatigue feelings) are shown in Fig. 4. A higher SAF-J score indicates a higher level of visual fatigue. The results of Group 5 for SAF-J for each display size are shown below.

1. 17-inch display: no significant effect of viewing distance was observed. And a significant effect of participant was observed \((F(3,15) = 6.000, p < 0.01)\). But these differences were independent from their ages.
2. 42-inch display: no significant effect of viewing distance was observed. And a significant effect of participant was observed \((F(3,15) = 3.102, p < 0.01)\). But these differences were independent from their ages.
3. 65-inch display: the score at 110 cm tended to be higher than at 220 cm: \((F(3,15) = 2.320, p = 0.09)\). And a significant effect of participant was observed \((F(3,15) = 6.068, p < 0.01)\). But these differences were independent from their ages. In addition, same as in Group 5 for SAF-J, the results for another subjective assessment were independent on their ages.

The results for Group 2 (erratic feelings) of SAF-J are shown in Fig. 5. A higher SAF-J score indicates a higher level of erratic feelings, including anxiety or irritation. Group 2’s results for SAF-J at each display size are shown below.

![Fig. 4. Score of subjective assessment of fatigue (SAF-J Group 5) at each viewing distance. A higher score indicates a higher eye fatigue evaluation. +: p<0.1](image_url)

![Fig. 5. Score of subjective assessment of fatigue (SAF-J Group 2) at each viewing distance. A higher score indicates a higher erratic feelings evaluation.](image_url)
size are shown below.
(1) 17-inch display: no significant effect of viewing distance was observed in Group 2 for SAF-J, although the score for Group 2 for SAF-J at 330 cm tended to be higher than at 165 cm. And no significant effect of participant was observed.
(2) 42-inch display: no significant effect of viewing distance was observed. And no significant effect of participant was observed.
(3) 65-inch display: no significant effect of viewing distance was observed. And significant effect of participant was observed (F(3,15) = 3.317, p < 0.01).

The results for Group 3 (nausea and headache) for SAF-J are shown in Fig. 6. A higher SAF-J score indicates a higher level of disagreeable feelings (headache and nausea, etc.: related to motion sickness). The results for Group 3 of SAF-J for each display size are shown below.
(1) 17-inch display: no significant effect of viewing distance was observed. And significant effect of participant was observed (F(3,15) = 2.469, p < 0.01).
(2) 42-inch display: The score at 165 cm tended to be higher than at 330 cm: (F(3,15) = 2.376, p = 0.08). And significant effect of participant was observed (F(3,15) = 4.058, p < 0.01).
(3) 65-inch display: a significant effect of viewing distance was observed (F(3,15) = 4.012, p = 0.02). In the post hoc test results, the score at 110 cm was significantly higher than that at 330 cm; (p < 0.01). And significant effect of participant was observed (F(3,15) = 2.799, p < 0.01).

The results for SAF-M are shown in Fig. 7. A higher SAF-M score indicates a higher level of visual fatigue. The SAF-M results for each display size are shown below.
(1) 17-inch display: The SAF-M score at 165 cm tended to be higher than at 220 cm; (F(3,15) = 2.334, p

![Fig. 6. Score of subjective assessment of fatigue (SAF-J Group 3) at each viewing distance. A higher score indicates a higher nausea and headache evaluation. +: p<0.1, **: p<0.01.](image)

![Fig. 7. Score of subjective assessment of fatigue (SAF-M) at each viewing distance. A higher score indicates a higher eye fatigue evaluation. +: p<0.1, *: p<0.05, **: p<0.01.](image)
And a significant effect of participant was observed (F(3,15) = 5.793, p < 0.01).

(2) 42-inch display: no significant effect of viewing distance was observed. And a significant effect of participant was observed (F(3,15) = 4.217, p < 0.01).

(3) 65-inch display: a significant effect of viewing distance was observed (F(3,15) = 5.406, p < 0.01). The result of a post hoc test showed the score at 110 cm to be significantly higher than that at 220 cm; (p < 0.05); the score at 110 cm was also significantly higher than that at 330 cm; (p < 0.05). And a significant effect of participant was observed (F(3,15) = 6.253, p < 0.01).

The results of subjective assessment are shown in Fig. 8, 9, and 10. For each display size, the results for items related to less mental fatigue, the results of feeling of involvement and the results of the total evaluation score are shown below. Participants also ranked viewing distances as 1st, 2nd, 3rd and 4th in descending order of preferred viewing distance. The rankings were used when calculating the evaluation scores: the first rank was allocated four points, the second, three, and so on. Higher scores indicated a higher evaluation (positive). This scoring was different from SAF-J or SAF-M. The results for items indicating less mental fatigue are shown in Fig. 8. A higher score indicates a positive evaluation (lower mental fatigue). The score for less mental fatigue at 220 cm was the highest among those at the four distances for each display size. The results for less mental fatigue for each display size are shown below.

(1) 17-inch display: no significant effect of viewing distance was observed in items indicating less mental fatigue. And no significant effect of participant was observed.

(2) 42-inch display: a significant effect of viewing distance was observed (χ2 = 16.65, χ2 (0.95) = 7.815, p < 0.001). And no significant effect of participant was observed.

(3) 65-inch display: a significant effect of viewing distance was observed (χ2 = 22.95, χ2 (0.95) = 7.815,
The results of the evaluation scores for each viewing distance for causing excitement or a feeling of involvement with the action are shown in Fig. 9. Higher scores indicate a positive evaluation (higher feeling of involvement). The results of a higher feeling of involvement item for each display size are shown below.

1. 17-inch display: a significant effect of viewing distance was observed in feeling of involvement items ($\chi^2 = 22.95$, $\chi^2 (0.95) = 7.815$, $p < 0.001$). And no significant effect of participant was observed.

2. 42-inch display: a significant effect of viewing distance was observed ($\chi^2 = 9.15$, $\chi^2 (0.95) = 7.815$, $p = 0.03$). And no significant effect of participant was observed.

3. 65-inch display: a significant effect of viewing distance was observed among 110, 165, 220 and 330 cm ($\chi^2 = 14.25$, $\chi^2 (0.95) = 7.815$, $p < 0.01$). And no significant effect of participant was observed.

The results of the total evaluation scores for each viewing distance are shown in Fig. 10. Higher scores indicate a positive evaluation. The results of total evaluation items for each display size are shown below.

1. 17-inch display: a significant effect of viewing distance was observed in total evaluation score ($\chi^2 = 27.98$, $\chi^2 (0.95) = 7.815$, $p < 0.01$). And no significant effect of participant was observed.

2. 42-inch display: a significant effect of viewing distance was observed ($\chi^2 = 33.3$, $\chi^2 (0.95) = 7.815$, $p < 0.01$). And no significant effect of participant was observed.

3. 65-inch display: a significant effect of viewing distance was observed ($\chi^2 = 27.75$, $\chi^2 (0.95) = 7.815$, $p < 0.01$). And no significant effect of participant was observed.

Typical comments made by some participants are shown in Table 2.

**Blinking rates**

Blinking rates were calculated as the rate recorded while resting after the test divided by the blinking rate before the test, expressed as a percentage. The results of the blinking rates for each viewing distance are shown in Fig. 11. Higher rates indicate greater visual fatigue. The results of blinking rates for each display size are shown below.

1. 17-inch display: The blinking rates at 220 cm were the highest among four distances, although no significant effect of viewing distance was observed in blinking rates. And a significant effect of participant was observed ($F(3,15) = 3.253$, $p < 0.01$). But these differences were independent on their ages.

2. 42-inch display: a significant effect of viewing distance was observed ($F(3,15) = 2.968$, $p = 0.04$). The result of a post hoc test showed the blinking rates at 110 cm to be significantly higher than that at 220 cm ($p < 0.05$). And no significant effect of participant was observed.

3. 65-inch display: The blinking rates at 110 cm was the highest among four distances; however, there was no significant effect of viewing distance was observed. And no significant effect of participant was observed.
Heart rate variability is an index of physical and mental strain: the higher the level of stress or mental excitement (Kobayashi, 2006), the higher the level of sympathetic nerve activity. Average LF/HF tended to rise with increasing display size. However, LF/HF at 165 cm was highest among 110, 165, 220 and 330 cm for each display size. The results of LF/HF for each viewing distance are shown in Fig. 12. The results of LF/HF for each display size are shown below.

<table>
<thead>
<tr>
<th>17-inch</th>
<th>42-inch</th>
<th>65-inch</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) A viewing distance of 165 cm is the best for TV viewing and reading kanji characters.</td>
<td>(1) 110 and 165 cm are good for looking at scenery, but it is hard to watch at 110 cm if there is a lot of motion in the video.</td>
<td>(1) A viewing distance of 220 cm is best for TV viewing and reading kanji characters, however, 330 cm is too far away for TV viewing or reading kanji characters.</td>
</tr>
<tr>
<td>(2) 165 cm is the best for watching news, and 110 cm is the best for watching video material.</td>
<td>(2) Although 110 cm gave a strong feeling of involvement, it also caused visual fatigue, similar to watching a movie in a theater.</td>
<td>(2) A viewing distance of 220 cm was overall the best of the four distances. A viewing distance of 110 cm for a 65-inch screen is too near to watch TV comfortably, since it tended to cause disagreeable feelings like motion sickness.</td>
</tr>
<tr>
<td>(3) A viewing distance of 330 cm for a 17-inch screen is too far away to permit convenient reading of text. This difficulty in reading caused sleepiness and lack of concentration.</td>
<td>(3) It is easy to read on-screen text at 110 and 165 cm, but hard at 330 cm.</td>
<td>(3) A viewing distance of 110 cm tended to cause visual fatigue, and the display was too bright and overpowering. However, increasing the distance from the screen reduces this feeling of being overwhelmed with colour and motion.</td>
</tr>
<tr>
<td></td>
<td>(4) The viewing distance that gives the greatest feeling of involvement is between 110 and 165 cm; however, 220 cm is the viewing distance that gives the most relaxed feeling.</td>
<td>(4) A viewing distance of 220 cm was the best of the four distances overall. However, 220 cm did not give a strong feeling of involvement: distances closer than 220 cm gave more feeling of involvement than at 220 cm.</td>
</tr>
</tbody>
</table>

Fig. 11. Blinking rates at each viewing distance. Blinking rates (relative blinking rates while resting after the test divided by blinking rates before the test at 100%). *: p<0.05 .

**LF/HF ratio of heart rate variability**

Heart rate variability is an index of physical and mental strain: the higher the level of stress or mental excitement (Kobayashi, 2006), the higher the level of sympathetic nerve activity. Average LF/HF tended to rise with increasing display size. However, LF/HF at 165 cm was highest among 110, 165, 220 and 330 cm for each display size. The results of LF/HF for each viewing distance are shown in Fig. 12. The results of LF/HF for each display size are shown below.

(1) 17-inch display: LF/HF at 165 cm tended to be higher than at 110 cm; (F(3,15) = 2.250, p = 0.09). And no significant effect of participant was observed.

(2) 42-inch display: a significant difference was observed in LF/HF among 110, 165, 220 and 330 cm (F(3,15) = 4.082, p = 0.01). The results of a post hoc test showed LF/HF at 165 cm to be significantly higher than that at 330 cm (p < 0.01). And no significant effect of participant was observed.

(3) 65-inch display: no significant difference was observed in LF/HF among 110, 165, 220 or 330 cm. However, LF/HF at 165 cm was the highest among the four distances, and LF/HF at 220 cm was the lowest among them. And significant effect of participant was observed (F(3,15) = 3.990, p < 0.01). But these differences were independent from their ages.
Critical flicker fusion frequency

No significant difference was observed among CFF values at 110, 165, 220 or 330 cm for 17-inch, 42-inch and 65-inch displays.

Effect of generations

As mentioned in each result part, no significant difference was observed in subjective assessment and physiological evaluation (blinking rates, heart rate variability (LF/HF), CFF) and task performance as measured by number of correct answers between generations for each TVs size.

DISCUSSION

In the case of Group 5 (Eye fatigue feelings) (Fig. 4) in the SAF-J, Group 3 (nausea and headache related to motion sickness) (Fig. 6) in the SAF-J, SAF-M (Fig. 7) and the results of the interview (Table 2), a viewing distance of 110 cm for a 65-inch screen appeared to be too close to watch TV comfortably, since the participants suffered visual fatigue and disagreeable feelings related to motion sickness. A viewing distance of around 220 cm for a 65-inch screen appeared to be the optimum viewing distance for less visual fatigue and comfortable watching.

For the 42-inch display, there was no significant difference observed in any of the SAF items among 110, 165, 220 or 330 cm. However, the score at 165 cm tended to be higher than that at 330 cm.

For the 17-inch display, no significant difference was observed in Group 2 (erratic feelings) (Fig. 5) for SAF-J among 110, 165, 220 or 330 cm, although the score for Group 2 for SAF-J at 330 cm tended to be higher than at 165 cm. A viewing distance of 330 cm for a 17-inch screen appeared to be too far away to permit convenient reading of text. We believe that this difficulty in reading caused sleepiness and lack of concentration, and made the SAF-J values in Group 2 higher than those at other viewing distances.

For the 42-inch display, the blinking rate at 110 cm was significantly higher than at 220 cm (p < 0.05), indicating 220 cm to be the optimal viewing distance for less visual fatigue physiologically (Yamada, 2001). However, for the 17-inch display and 65-inch display, no significant differences were observed in blinking rates among 110, 165, 220 or 330 cm. On the other hand, in the case of SAF-J and SAF-M, there were significant differences observed among 110, 165, 220 and 330 cm; and taking into account the results of the interview, a viewing distance of 330 cm for a 17-inch screen appeared to be too far away to permit convenient reading of text. We believe that this difficulty in watching caused sleepiness and lack of concentration, resulting in no significant differences being observed among distances physiologically. Moreover, a viewing distance of 110 cm for a 65-inch screen appeared to be too near to watch TV comfortably. It is possible that the participants felt visual fatigue and disagreeable feelings related to motion sickness; and this difficulty in watching caused a lack of concentration that affected blinking rates. Thus, when a
significant difference was observed psychologically among distances, even if there was no significant difference physiologically among them, it is conceivable that some form of physiological or behavioural compensation action worked to reduce the influence on the eyes and body (for example, looking away by moving one’s gaze to the edge of the display). It therefore would seem to be necessary to make an overall evaluation based on both the physiological and psychological results. Moreover, the visual contents used in this study were not of the type that required participants to stare steadily, thus it might be difficult to observe significant difference among those distances physiologically. Further investigation appears to be necessary to select or develop visual content.

On the other hand, the average LF/HF tended to rise with increasing display size. However, LF/HF at 165 cm was the highest among 110, 165, 220 and 330 cm for each display size. For the 42-inch display, LF/HF at 165 cm was notably and significantly higher than that at 330 cm. The results of the interviews suggest 165 cm to be the optimum viewing distance for causing excitement or a feeling of involvement with the action, but this distance is not related to display size. It is possible that the increased visual workload also influences the level of sympathetic nerve activity (LF/HF) (Hayashi et al., 2009; Shimono et al., 1998; Okada et al., 2005). However, in this case, no significant difference observed among those distances for blinking rate, although the level of sympathetic nerve activity (LF/HF) peaked at 165 cm. These results suggest that the extra workload might to some extent influence due to mental excitement including a feeling of involvement better than visual fatigue (Kobayashi, 2006; Nojiri, 2005; Sakuragi et al., 2002).

The score for less mental fatigue at 220 cm was the highest among those at the four distances for each display size. The score for feeling of involvement at 165 cm was the highest among these distances for 42-inch and 65-inch displays, although the score for feeling of involvement at 110 cm was the highest among those distances for the 17-inch display. Moreover, the total evaluation score at 165 cm was the highest among the four distances for 17-inch displays and that at 220 cm was the highest among those distances for the 42-inch and 65-inch displays. In the light of the SAF results and the results of the interviews, it appears that the subjective optimum viewing distance falls between 165 and 220 cm, irrespective of display size. However, concerning the subjective optimum viewing distance, some participants felt that the optimum viewing distance depended on the content and their viewing mood.

In this study, the effect of viewing distance on visual fatigue showed wide variations between participants. However it was difficult for one participant to perform the tests for three display types considering testing time, work load and boredom caused by watching the same program several times a participant. For this reason, as a statistical analysis two-way ANOVA without replication was performed, interaction could not be observed between viewing distance and participants. It is thus necessary to further investigate the relationship between viewing distance and participants. And as the reason why no significant difference was observed in subjective assessment and physiological evaluation between generations, the range of generations might be limited. It is thus necessary to further investigate the relationship between those, using various age of generations.

Moreover, the results of the subjective assessment and physiological evaluation showed wide variations. It will be necessary to examine methods for improving the accuracy of the subjective evaluations. For this reason, it is conceivable that the variations are caused by differences in visual acuity or habitual viewing distance, or differences between individuals in feeling of involvement in the content and tasks. It is thus necessary to further investigate the relationship between visual fatigue and a feeling of involvement, and between visual fatigue and viewing distance, as well as methods for improving the accuracy for measuring or controlling feeling of involvement.

Regarding viewing distance, currently the recommended distance for high-definition TVs is 2 or 3 times the display’s height (Narita et al., 2001). The recommended value for the optimum viewing distance was obtained by making the viewer less aware of individual pixels; thus the evaluation methods were based on subjective evaluations, not on objective gauges such as physiological measurements (ITU-R, 1998; ITU-R, 1997). In our previous study (Sakamoto et al., 2009), task performance rates and horizontal EOG were significantly affected by physical factors such as viewing angle or awareness of individual pixels related to relative viewing distance (H). However, it is necessary to explore whether the relative viewing distance (calculated viewing distance based on display height, H) might be adapted to the optimum viewing
distance for less visual fatigue and a closer feeling of involvement. This is because visual fatigue and a closer feeling of involvement might be affected by mental and physiological factors. Considering the results of subjective evaluations, including interviews, the physiological and psychological indices adopted in this study are potentially accurate indices for measuring visual fatigue that still take into account the viewer’s feelings of involvement with the action on the screen.

However, LF/HF and blinking rates, including amplitude rates and SAF, were not correlated with relative viewing distance (H). However, this study’s results, based on physiological and psychological measurements, showed that the psychological optimum viewing distance lied between 165 and 220 cm, and that sympathetic nerve activity peaked at around 165 cm, irrespective of screen size.

Moreover, as suggested by the results of evaluations based on optimum viewing distance for less visual fatigue and closer feeling of involvement which might be affected by mental factors and thus might not follow the currently recommended relative distances, it might be necessary to define the recommended distances as absolute distances and not to use a formula.

Moreover, in this study, since it takes considerable time and expenses to obtain physiological and psychological data from each participant, the number of participants was limited to 16 persons for each display size. For this reason, rather than increasing the number of participants, our results were obtained by a statistical analysis.

Wang et al. (2003, 2000) and Oetjen et al. (2009) investigated the effects of display type and luminance and contrast on visual performance using searching tasks or reading tasks. In our study, however, the viewing distances and display size were controlled, and different experimental conditions were set as constants. The main aim of the tasks was not to test for visual performance but to prevent sleepiness and maintain arousal above a certain level.

In this study, display size and viewing distance were varied, making it possible to investigate the effects of various display types and luminance and contrast on visual fatigue, as well as the relationship between feeling of involvement (which might increase with increasing TV screen size) and visual fatigue with different types of viewing styles and different participant ages, exemplified by the trend towards larger displays and the use of TVs as 3DTV and PC display devices. Longer-term experiments and field tests will also be necessary to investigate these questions in more detail in future studies.

CONCLUSIONS

The current recommended viewing distance for high-definition TVs is currently 2 or 3 times the display height. However, this study’s results, based on physiological and psychological measurements, show that the optimum viewing distance lies between 165 and 220 cm, irrespective of screen size. We conclude that evaluations based on optimum viewing distances that minimize visual fatigue and give a closer feeling of involvement are affected by a range of factors, and thus may not follow the currently recommended relative distances.

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REFERENCES


