Parameter Comparison of Assessing Visual Fatigue Induced by Stereoscopic Video Services

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Abstract. A number of three-dimensional (3D) video services have already been rolled out over IPTV. In 3D video services, there are concerns that visual fatigue still exists, so evaluation of visual fatigue induced by video compression and delivery factors is necessary to guarantee the safety of 3D video services. To develop an assessment method of visual fatigue, we conducted evaluation experiments designed for 3D videos in which the quality of the left and right frames differ due to encoding. We explain the results from our evaluation experiments of visual fatigue, that is, results of specific parameters of visual fatigue biomedical assessment methods.

Keywords: 3D video, quality assessment, visual fatigue, encoding.

1 Introduction

Three-dimensional (3D) movies have become popular worldwide. A number of manufacturers have already put 3D televisions into the market, and the market for 3D-video-related products is surging. 3D broadcasting has been made available in markets around the world, and a number of 3D video services have already been rolled out over IPTV ([1], [2]). 3D broadcasting and 3D video services over IPTV use limited transmission bandwidth (i.e. bit-rate). Therefore, to provide high-quality 3D video services, it is important to compress and transmit information effectively.

Image safety (e.g. visual fatigue and visually induced motion sickness) as well as image quality concerns with conventional 2D video services must be considered for quality of 3D video services. Although 3D movies have become popular, concerns for image safety still exist. For example, the National Consumer Affairs Center of Japan received inquiries and complaints from people regarding visual fatigue after watching 3D movies [3]. Therefore, visual fatigue problems are important issues to consider. For service providers to provide high-quality 3D video services, 3D service design and management based on evaluation of image safety as well as image quality are important.

Visual fatigue is caused by a number of factors such as content production, video compression and delivery, and viewing environment (Fig. 1). Because a number of 3D video services have already been rolled out over IPTV, evaluation of visual

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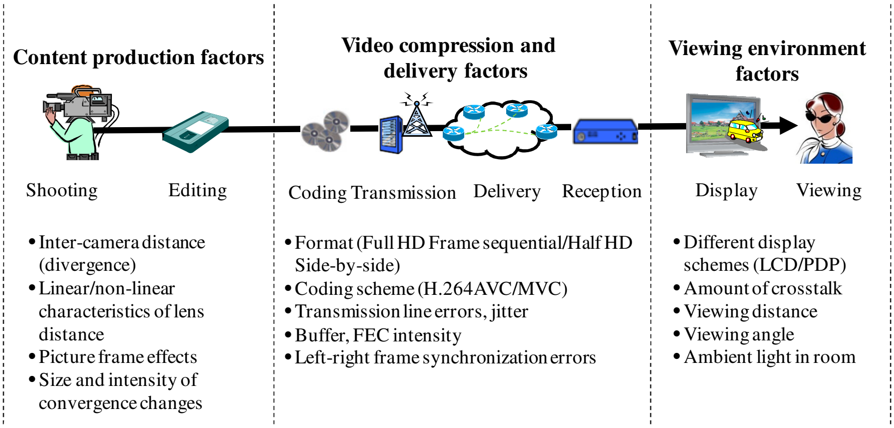

Fig. 1. 3D video processing chain

fatigue induced by video compression and delivery factors is necessary to guarantee the safety of 3D video services. The 3D Consortium (3DC) Safety Guidelines for Dissemination of Human-friendly 3D [4] defined safety guidelines for content production and viewing environment factors. Therefore, users are able to watch safe 3D content in a safe viewing environment. However, even if safe 3D content is delivered, video compression and delivery factors may bring about visual fatigue. Video compression and delivery factors are critical for safe 3D video services. A previous study on visual fatigue focused on content production and delivery factors [5, 6, 7]; however, there have been few studies that have focused on video compression and delivery factors. Recently, 3D video service providers have discussed new 3D video compression and delivery methods to achieve higher image quality with lower bit-rate. Service providers are concerned that the difference between the left and right frame quality induces visual fatigue. Therefore, our aim is to evaluate visual fatigue induced by video compression and delivery factors. Using our results of visual fatigue evaluation, we plan to develop video compression and delivery methods to achieve higher image quality and lessen visual fatigue. In addition, as a telecom company, we aim to provide safe 3D video services.

This paper is organized as follows. Previous studies related to evaluation of visual fatigue is explained in Section 2. We discuss the experimental methods and results in Section 3. Finally, the conclusion and further studies are described in Section 4.

2 Related Work

There are quality assessment methods for visual fatigue. For example, the Simulator Sickness Questionnaire (SSQ) is used to evaluate visually induced motion sickness and viewing fatigue, and the Visual Analogue Scale (VAS) is used to evaluate relief from fatigue by requiring the consumption of certain healthy food. However, these methods are targeted for people who feel extreme exhaustion. On the other hand, biomedical assessment methods evaluate viewer sensitivity or comfort by measuring their vision. For example, experiments have been conducted on visual fatigue induced

Table 1. Biomedical assessment parameters

Parameters
Critical Fusion Frequencies (CFF)
Vision binocular vision, simultaneous perception, position of eye, and fusion
Eye-blink
Pupil constriction rate

Table 2. 3D videos

	video 1	video 2	video 3	video 4
Left image quality	Reference	Reference	Reference	Reference
Right image quality	Reference	6 Mbps	3 Mbps	1 Mbps

by 3D monitors and content, and Visual Display Terminal (VDT) tasks using biomedical assessment methods [8-12]. However, no generalized index of visual fatigue has been established. Therefore, our aim was to choose specific parameters of biomedical assessment methods that can be used to assess visual fatigue with a high degree of accuracy, similar to conventional subjective quality assessment methods.

3 Visual Fatigue Evaluation Experiments

3.1 Methods

As explained above, we conducted visual fatigue evaluation experiments by using the biomedical assessment methods with several parameters listed in Table 1. These parameters are said to be able to evaluate visual fatigue [4, 9-12]. Our aim was to choose specific parameters of biomedical assessment methods that can evaluate visual fatigue induced by 3D videos in which the quality of the left and right frames differ due to encoding.

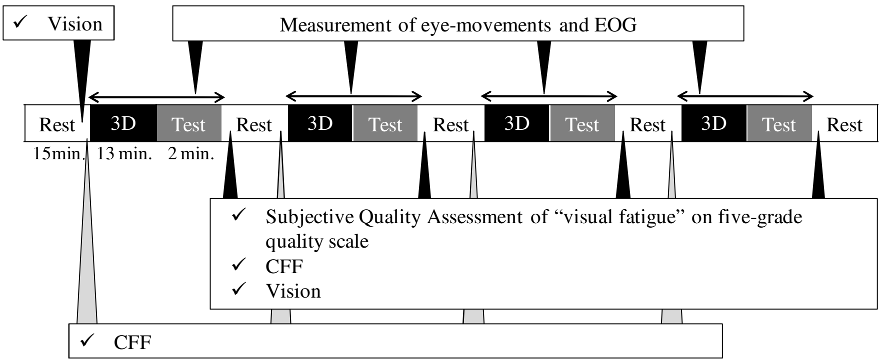

Fig. 2. Flow of our experiment

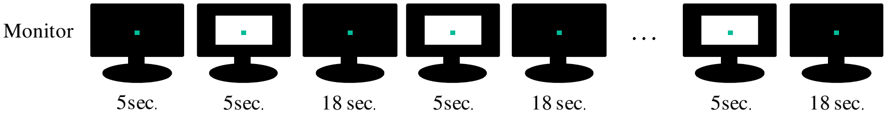

Fig. 3. Sequence of test video

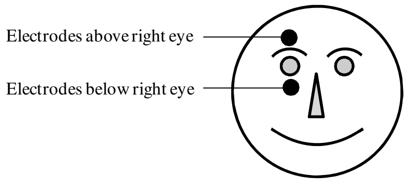

Fig. 4. Schematic representation of electrode locations for EOG recording

In our experiment, 13 participants watched 3D videos of around 13 minutes. Participants viewed each video sequence at a distance of 3 H (3 H is about 200 cm, H indicates the ratio of viewing distance to picture height) from a 46-inch 3D monitor. The participants viewed the 3D video with polarized glasses. The room luminance was 20 lux. We used the 3D content, "2028:Belief" provided by the Digital Content Association of Japan (DCAJ) [13]. This 3D content is produced in compliance with 3DC Safety Guidelines [4] in order to exclude visual fatigue caused by 3D content. This content is about 13-minute drama. We used this content and prepared four kinds of 3D videos based on the hypothesis that the greater the difference between the left and right frame quality in the 3D videos, the stronger the feelings of visual fatigue; one 3D video had the same quality on the left and right frames, and the other three had different quality between the left and right frames due to encoding (Table 2). In Table 2, "Reference" means the source video, and "x Mbps (x=1, 3, 6)" means the bit rate of encoding the source video. After watching each 3D video, participants watched the test video in order to measure pupil diameter stable. We show the flow of our experiment in Fig. 2 and the sequence of the test video in Fig. 3. In Fig. 3, the green point was the point of gaze, and the black and white image was presented alternately about 5 times.

We measured eye movement for recording pupil diameters and sight direction, and electro-oculogram (EOG) for counting the number of eye-blinks while participants were watching the 3D videos. We attached electrodes above and below the right eye to record the EOG shown in Fig. 4. We then measured critical fusion frequencies (CFFs) before and after they watched the 3D videos, and vision (e.g. binocular vision, simultaneous perception, position of eye, and fusion) after they finished watching the 3D videos. In addition, participants evaluated their feelings of "visual fatigue" on a five-grade quality scale after they had finished watching the 3D videos. We presented the four 3D videos randomly for each participant.

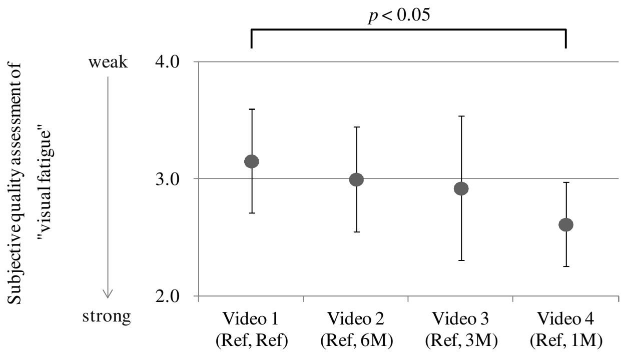

Fig. 5. Results of subjective quality assessment methods of "visual fatigue"

3.2 Results

To choose specific parameters of biomedical assessment methods that can evaluate visual fatigue induced by 3D videos in which the quality of the left and right frames differ due to encoding, we compared the biomedical assessment methods' results. In particular, we compared the results of when participants felt strong visual fatigue with those of when they felt weak visual fatigue. We hypothesized that participants felt stronger visual fatigue after they watched video 4 in which there was the largest difference in left and right frames, as described in Section 3.1. In fact, our results of subjective quality assessment of "visual fatigue" showed that the greater the difference between the left and right frame quality in the 3D videos, the lower the grade of subjective quality assessment of "visual fatigue", which means the stronger their feelings of visual fatigue (Fig. 5). We used 13 participants' data. Error bars represented 95% confidence intervals. There was a significant difference of 5% between videos 1 and 4 in the paired t-test.

Therefore, we compared the biomedical assessment methods' results when participants watched videos 1 and 4. We then chose the biomedical assessment parameters that could evaluate the visual fatigue of videos 1 and 4 by about 5% significant difference using the paired t-test. This means that the biomedical assessment parameters we chose can match the accuracy of the conventional subjective quality assessment methods of "visual fatigue" described above.

Table 3. Definition of mean CFF values

Measurement timing of CFF	Definition
Mean CFF values before participants watched video x (x=1,2,3,4)	$CFF_{video\ x\text{-}pre}$ (x=1,2,3,4)
Mean CFF values after participants watched video x (x=1,2,3,4)	$CFF_{video\ x\text{-}post}$ (x=1,2,3,4)

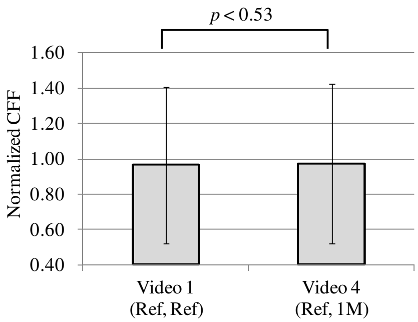

Fig. 6. Results of normalized CFF

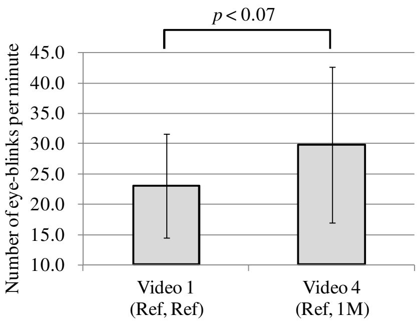

Fig. 7. Results of eye-blinks

3.2.1 CFF

In this section, we explain the results of CFF and consider whether CFF can be used to evaluate visual fatigue.

We used 13 participants' data in which there were no loss. We measured the frequencies in which participants could not detect flicker when the frequency was increased from 20 Hz and that in which the participants could detect flicker when the frequency was decreased from 60 Hz frequency. We measured both frequencies three times and calculated the mean CFF values of these frequencies. To reject individual differences, we defined the mean CFF values, which are listed in Table 3. Then, we defined the normalized CFF ($nCFF_x$) in Eq. (1).

$$nCFF_x = CFF_{video\ x\text{-}post} / CFF_{video\ x\text{-}pre} \quad (x = 1,2,3,4) \tag{1}$$

We show the results of normalized CFFs in Fig. 6. Error bars represented 95% confidence intervals. According to Fig. 6, there was a significant difference of 53% between videos 1 and 4 in the paired t-test. This result did not match the accuracy of the conventional subjective quality assessment methods of "visual fatigue". Therefore, CFF was not able to evaluate visual fatigue induced by 3D videos in which the quality of left and right frames differ due to encoding.

3.2.2 Eye-Blink

In this section, we explain the results of eye-blink and consider whether eye-blink can be used to evaluate visual fatigue.

We used 11 participants' data in which there were no loss. Using the results of the EOG measurement, we calculated the number of eye-blinks per minute while they watched 13-minute 3D videos. Our results showed that the greater the difference between the left and right frame quality in the 3D videos, the greater the number of eye-blinks (Fig. 7). Error bars represented 95% confidence intervals. In addition, there was a significant difference of 7% between videos 1 and 4 in the paired t-test. This result matched the accuracy of conventional subjective quality assessment methods of "visual fatigue". Therefore, we determined that eye-blink could be used to evaluate visual fatigue induced by 3D videos in which the quality of left and right frames differ due to encoding.

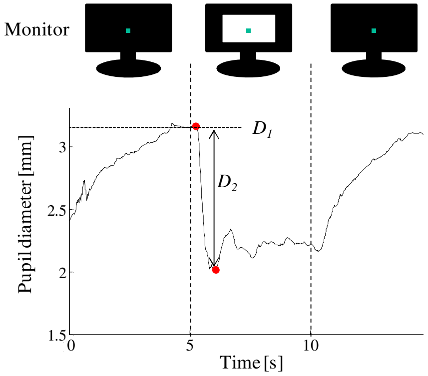

Fig. 8. Analytical terms of pupil measurement

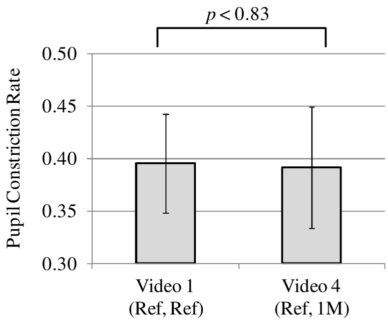

Fig. 9. Results of pupil constriction rate

In a previous study, the results showed that the number of eye-blinks was higher when watching 3D video than in 2D video [10]. Another study gives the conclusion that the number of eye blinks was higher when viewing the 3D video with moderate visual fatigue than with low visual fatigue [9]. Therefore, our results are consistent with the results of previous studies and eye-blinking is considered as an indicator for measuring visual fatigue.

3.2.3 Pupil Constriction Rate

In this section, we will proceed with the analysis of eye-movements and consider whether pupil diameter and other parameters of eye-movements can be used to evaluate the visual fatigue or not.

We used 8 participants' data in which there were no loss. We analyzed in terms of the pupil diameter (D_1) and the amplitude of pupillary constriction (D_2), as shown in Fig. 8 . Then, we defined the pupil constriction rate (CR) in Eq. (2).

$$CR = D_2 / D_1 \tag{2}$$

Table 4. Results of parameter comparison

Parameters	Judgments	*p*-value
CFF	No	$p = 0.53$
Vision binocular vision, simultaneous perception, position of eye, and fusion	No	These did not changed according to the 3D videos that participants watched.
Eye-blink	Yes	$p = 0.07$
Pupil constriction rate	No	$p = 0.83$

We show the results of pupil constriction rate in Fig. 9. Error bars represented 95% confidence intervals. According to Fig. 9, there was a significant difference of 83% between videos 1 and 4 in the paired t-test. This result did not match the accuracy of conventional subjective quality assessment methods of "visual fatigue". Therefore, we determined that pupil constriction rate could not be used to evaluate visual fatigue induced by 3D videos in which the quality of left and right frames differ due to encoding.

3.2.4 Results of Parameter Selection for Developing Visual Fatigue Assessment Methods

In this section, we summarize the results of our parameter selection given in Sections 3.2.1, 3.2.2 and 3.2.3. Table 4 listed the results of parameter comparison. According to Table 4, we determined that out of the parameters we measured and analyzed eye-blink is a possible parameter for assessing visual fatigue induced by 3D videos in which the quality of left and right frames differ due to encoding.

4 Conclusion

We conducted visual fatigue evaluation experiments by using the biomedical assessment parameters (CFF, vision, eye-blink, and pupil constriction rate) to evaluate visual fatigue induced by video compression and delivery factors. We compared the biomedical assessment parameters' results when participants watched video 1, in which there was no difference in left and right frames, and video 4 in which there was the largest difference in left and right frames. We chose biomedical assessment parameters that can be used to evaluate the visual fatigue with about a 5% significant difference using the paired t-test, and that match the accuracy of the conventional subjective quality assessment methods of "visual fatigue". Out of these parameters, eye-blink is a possible parameter for assessing visual fatigue induced by 3D videos in which the quality of left and right frames differ due to encoding. In the future, we will develop objective visual fatigue evaluation methods based on eye-blink in order to develop video compression and delivery methods to achieve higher image quality with lower bit-rate and lessen visual fatigue.

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