LETTER *Special Section on Image Media Quality*

Analysis of Eye Movement and Critical Fusion Frequency Responses to Different Movie Types

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SUMMARY We can enjoy various video contents such as movies in several ways. In this report, we show the effects of content differences on physiological parameters such as eye movements and CFF. This time we confirmed the difference in responses that after watching a movie. In addition, a consistent change that can infer that due to a movie was also indicated. Our results showed that content differences affect the parameters. This suggests the possibility that the influence of movie contents on the viewer can be evaluated by physiological parameters.

key words: *movies, eye movements, gazing point, saccades, CFF*

1. Introduction

Telecommunications advancements have enabled people to enjoy video contents in various situations. Nowadays, video contents have spread to TV as well as the Internet. There is an enormous amount of video content such as advertisements; also, video content that affects feelings such as movies. Since the use of online services and devices such as smartphones have become widespread, opportunities to watch video content are increasing. There are many reports that mind and body parameters influence eye function [1], [2]. Some studies of eye movements for physiological evaluation have been reported in the medical field [3]–[5]. In this study, we investigated how movies affect physiological parameters such as a stability of gazing, saccade latencies and CFF.

2. Eye Movements

Eye movements are driven by the extraocular muscles: namely, four rectus muscles and two oblique muscles. These movements can be categorized as binocular or monocular. Moreover, the latter can be classified as fixation eye movement, pursuit eye movement and saccades. Fixation Eye Movements: Our eyes continually move even when our gaze is fixed on a stationary point. Various research has indicated that fixation eye movement is influenced by the degree of attention and its direction [6]. This movement can be classified into three types. (1) Tremors: the tiniest movement, (2) Drifts: slightly larger and slower than Tremors, (3) Microsaccades: the largest movement. If these movements are completely stopped, the visual image disappears [7]. Saccades: the fastest eye movement for changing a gazing point. The latency is more than 0.2 sec generally [8], and it is shortened by anticipating the direction of movement [9].

3. Measurement Method of Eye Movements

We used Tobii Eye Tracker 4C (Tobii Technology) as a contactless gaze measurement, with a PC (FRONTIER FRXN770/C). The sampling rate was 90 Hz and the tracker can be installed on the bottom of a monitor. Subjects do not need to wear the device on their body; thus, it measures eye movement in a natural state. Visual line data is output as a pixel value; we converted the pixel value into a degree value with viewing distance and pixel pitch. The pixel pitch of the monitor we used (Mitsubishi Electric Corporation RDT231WLM) was 0.265 mm. This device shows the best accuracy when the subject gazes at the center of the screen or its vicinity [10]. We confirmed that some individual differences such as the degree to which the subject's eyelids were open and whether the subject was wearing glasses affected the detection accuracy. Especially, the accuracy loss was remarkable at the bottom of the screen when subjects were gazing at the bottom of the screen with lowered eyelids.

4. The Experimental Conditions

We measured eye movement and CFF before and after the movie to evaluate the effects of watching a movie on these parameters. The subjects were ten students (21 or 22 years old) who had no problems with stereopsis; from among them, eight subjects whose eye movement data could be properly acquired were analyzed. We used two movies in this experiment, the Walt Disney movie Tangled (100 min- Tou no ue no Rapunzel in Japanese) and the James Cameron film Avatar (160 min). The former is short and does not have fast movement. The latter is a relatively long movie with energetic movement. We divided the subjects into two groups to compare effects from difference of movie type. The subjects watched either Avatar or Tangled. Before the first measurement, we spent about 10 minutes to calibrate gaze measurement device and to instruct a subject in the same environment as the measurement for a subject to adapt

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the watching environment. Thus, the measurement was performed after the subject got used to the room environment such as room illuminance. After starting the measurement, we confirmed orally that a subject could fuse 3D image with the title displayed by 3D and the subject started watching a movie. In addition, we checked again orally that they could fuse 3D image clearly after 3 minutes from the start of watching. The measurement after watching was also performed promptly in about 1 to 2 minutes from the movie end. This experiment was conducted according to the Ethics Committee Regulations for Tokai University "Study Involving Human Subjects".

4.1 The Watching Movie Environment

The experiment was performed in a soundproof shield room. An air conditioner was running during the movie viewing to keep a constant temperature. The room temperature was kept between 23 and 24 degrees Celsius, humidity at 47% to 49% and room illuminance was 69.7 Lux, with the light turned off when the subject was watching the movie. The projector (SONY VPL-VW500ES) displayed the movies on a screen that was 262 cm wide by 147 cm high. The viewing distance was 440 cm. This value is about three times the screen height, which is the standard viewing distance of Full Hi-Vision. The maximum screen brightness was 104 cd/m^2, and the lowest screen brightness was 0.04 cd/m^2. Subjects wore liquid crystal shutter glasses and watched 3D movies. We set the volume of the movie at about 75 dB or less in *Tangled*. We presented *Avatar* to the subjects with the same setting as *Tangled*; however, the volume increased about 3 to 5 dB due to the movie difference.

5. Measurement Conditions

This section describes the measurement condition and equipment. We controlled subjects' eye movements with an indicating program which displayed a circular index (hereinafter, called the "Fixation target"). The fixation targets displayed at the specified positions in the monitor. Figure 1 shows the display order and position of the targets. Only one target at a time is indicated, and it moves to the next position after 5 seconds. Subjects are instructed to gaze at the target as it appears. When the target changes positon, subjects must track it with their eyes and continue to gaze at it. We set up a chin support to stabilize the head at a distance 60 cm from the monitor. The room illuminance during eye movement and CFF measurement is 82.5 Lux, and the luminance of the display is 78.92 cd/m^2 (white), 1.98 cd/m^2 (black), and 41.76 cd/m^2 (red circular index in Fig. 1). Before the first measurement, subjects practiced with targets for the training. They were instructed to track instantly after the display appeared, rather than to memorize or predict the position.

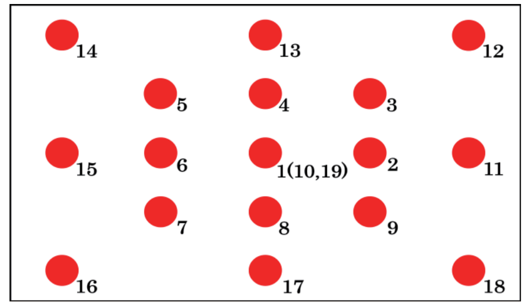

Fig. 1 Image for fixation target position.

5.1 Stimulus and Definition of Eye Movements

The fixation target (0.7 deg in diameter,) was displayed to the subjects. The distance between the fixation targets was 9.5 deg in the horizontal direction and 4.3 deg in the vertical direction. The display time of single target was 5 seconds. The first second (0–1 second) was considered the "tracking phase" for the target tracking and the next 4 seconds were considered the "gazing phase", when the subjects were gazing intensively. The tracking phase contains a saccade component. The gazing phase contains the component of a gazing point. To extract only saccades from gaze data when a subject is watching an image is very difficult [11]. However, the subject's eye movement was controlled by the target. Hence, we regarded saccades as not occurring except when the subjects moved from one target to the next target. The starting point of the saccade was one sample point before the first movement that exceeded the velocity threshold of 30 deg/sec [7]. Next, we show the gazing data extraction method for gazing point analysis. The range of the gazing point when watching an image has been reported to be about 2 deg [12]. However, this study displayed the target on a screen, a suitable range would be less than 2 deg. We set a 1.5 deg range with reference to the study of Kohama [1] (hereinafter, this range is called "fixation point"). The center of the fixation point is the average coordinate value determined by 4 seconds' coordinate data. Samples within the fixation point are termed "components of the gazing point" We excluded samples that exceeded the range.

5.2 Critical Fusion Frequency (CFF)

CFF is a higher-order visual characteristic occurring in the cerebrum, and it decreases with fatigue. The lowering of the CFF value is considered a useful indicator of central fatigue [13]. We measured CFF with the flicker fusion apparatus TKK-501c (Takei Scientific Instruments Co., Ltd.) and used CFF values as one element of the physiological evaluation. This apparatus is based on the standard flicker value measurement apparatus which is defined by the Industrial fatigue research association Japan [14], [15]. The illumination level of flicker field is 500 Lux ±10% (about 120 cd/m^2) and illumination level of peripheral field is 100 Lux ±40% (about 25 cd/m^2). The CFF threshold value was measured using the following two methods. Ascending method: when a light blinks slowly, subjects are able to discern the light flickering, but as the flickering becomes faster, it seems to disappear.

Table 1 Changes in gazing stability (standard deviation).

Subject	Title	Before	After	Tendency
A	A	0.30deg	0.23deg	improved
B	A	0.20deg	0.19deg	improved
C	A	0.74deg	0.88deg	worsened
D	A	0.37deg	0.43deg	worsened
E	T	0.53deg	0.59deg	worsened
F	T	0.47deg	0.32deg	improved
G	T	0.32deg	0.23deg	improved
H	T	0.75deg	0.47deg	improved

Descending method: the inverse of ascending method.

6. Result of Analysis

The subjects were divided into two groups for analysis. Subjects A to D in Tables 1, 3, 4 and Fig. 2 comprise the group that watched *Avatar*, and E to H comprise the group that watched *Tangled*. The abbreviations "A" and "T" in the table indicates the movie that the subject watched.

6.1 Analysis of Gazing Point and Its Stability

The gazing point analysis was performed on the target of the inner circumference where the subjects were able to maintain an accuracy of 1.5 deg stably (the target 2 to 10 in Fig. 1). Table 1 shows the standard deviation of gazing at the fixation target. These standard deviation values are evaluated as the degree of gazing stability. The tendency in Table 1 shows whether the stability of gazing has improved or not, For example, "improved" means the subject's gazing has stabilized after watching. The analysis showed that the changes after watching differed according to subject, even among those watching the same movie. Three of four subjects who watched *Tangled* showed the same change. Subject E was the only subject whose CFF declined after watching. Hence, it is expected that a different change occurred in this case; the details of subject E will be described in the Sect. 6.3. As three of the four subjects who watched *Tangled* showed a consistent tendency. Thus, the possibility that consistent influences occur by movie could not be denied.

6.2 Analysis of Saccade Latency

Changes in latency from the appearance of the target to the occurrence of saccades are shown in Table 2. These latencies are average values for each group (*Avatar* or *Tangled*). Subjects watching the movie *Avatar* responded more quickly after the movie while the latencies of the Tangled group became longer (slower) after the movie. We thought that the differences in effect may have been caused by the movie motion and scenario differences. *Tangled* is an animated fairy tale in which the main characters and others find happiness. On the other hand, *Avatar* is an action movie with the theme of fighting a war to achieve peace with visual aspects that are at once realistic, bold and fantastical. The changes in latency can be inferred as being caused by the difference between

Table 2 Changes in saccade latencies (group average value).

Title	Before	After
Avatar	307.1 msec	303.3 msec
Tangled	272.4 msec	288.3 msec

Table 3 Comparison of gazing stability and latency.

Subject	Gazing stability	Latency
A	improved	lengthened
B	improved	shortened
C	worsened	shortened
D	worsened	shortened
E	worsened	shortened
F	improved	lengthened
G	improved	lengthened
H	improved	lengthened

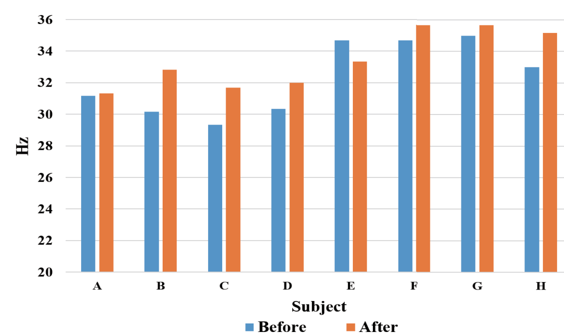

Fig. 2 Transition of CFF value.

inducing excitement (*Avatar*) or calm (*Tangled*) in the subjects. We conducted a paired t-test to each group for analyzing the results, and a significant difference between pre- and post-movie was confirmed in the group of *Tangled* ($p<0.05$). Therefore, it can be said that latencies of the *Tangled* group became significantly longer by movie watching. In addition, when we compared the gazing stability and the tendency of the latency, we found a connection in almost all the subjects. Table 3 shows whether the stability of gazing has improved or not, and the latency shows whether the saccade latency became shortened or not after watching. For example, in the case of subject A, the gazing has stabilized and the latency became longer after the movie. An inverse relationship was suggested whereby the latency became longer when the gazing stability was improved and the latency became shorter when the gazing stability was decreased.

6.3 Analysis of CFF Value

Figure 2 compares the average values of before and after watching the movie and Table 4 shows the time which first measurement was taken. We have not specified time, however, an influence of CFF values by the time was not shown. Improvement of the CFF value after watching was confirmed except in subject E. Generally, CFF would decrease due to fatigue caused by a task. However, in this experiment, almost all the subjects improved. We thought that this phenomenon occurred because the movie had a good effect (i.e., a relaxing

Table 4 Start time of the first measurement (24-hour clock)

Subject	A	B	C	D	E	F	G	H
Time	15	15	11	19	15	15	17	11

or stimulating effect) on their minds. Importantly, Subject E had never watched a 3D movie before, so it can be inferred that the subject E's decrease was caused by that subject state. The results of the eye movement analysis of this subject were also different from those of the other subjects. Therefore, it is expected that many subjects enjoyed the movie under suitable conditions e.g., at a suitable viewing distance and large screen in a quiet room can have a positive influence on the subject's psychological state. 3D causes fatigue mainly due to inconsistency of convergence and accommodation. An influence appears when people look an image that contradicts the focal length and the convergence distance [16]. From the result of CFF analysis, we inferred that watching a long 3D movie does not necessarily lead to fatigue.

7. Discussion

We investigated the influence of different genres of movies on physiological parameters such as eye movement and CFF. As a result, it was suggested that the difference in the presentation and contents of a movie may influence gazing stability and saccade latency. In the group that watched *Tangled*, consistent changes such as gazing stability improvement and the latency increase occurred except for a subject with reduced CFF. In the *Avatar* group, the overall trend had not statistically significant; however, the latency became slightly shorter after watching. We believe that these different phenomena were caused by changes in emotions and attention level due to the contents of the movies. Various studies have reported that the frequency and motion of saccades and microsaccades are affected by attention degree [1], [2], [9]. Moreover, an experiment performed on monkeys showed that there is a neuron that maintains a strong gazing in the superior colliculus, and this neuron has an antagonistic effect on saccadic neurons present in the superior colliculus [17]. Therefore, a strong gaze can be expected to delay the occurrence of saccades. In other words, if gazing at the target is steadier, saccade delay occurs. It has been found that the saccade latency of children with attention deficit hyperactivity disorder (ADHD) is slower than typically developing children [18]. In addition, it is anticipated that the motion of saccades is influenced from not only the superior colliculus but also the central nervous system affecting the CFF [19]. The occurrence of saccades is related to the orbitofrontal cortex [20], which governs emotions and decision-making [21]; hence, it makes sense that emotional changes might influence saccades. Watching a movie had a positive influence on the subject's mental state. However, while fatigue did not appear in the CFF, other symptoms of physical fatigue such as foot pain, lower back pain and eye strain due to long-term watching was confirmed by the questionnaire. Therefore, it can be said that not only the contents of the movie, but also the running time of the movie could affect a subject's psychological states. In this study, we used the same target and position for all measurements. Thus, there is a possibility that the subject's condition such as habituation affected the latency. As a future task, we should verify with a random targeting for confirming the same phenomenon occurs. Moreover, investigation by other kind of movie and comparison when showing different movies to the same subject are essential for research effects from video contents. Also, since we started an experiment just after calibration and explanation this time, we think that it will be interesting to do the experiment after we take enough time for a subject to adapt the watching environment of the movie.

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