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Paper

Investigation of the Influence of Display Type on Smooth Pursuit Eye Movement when Viewing a Moving Image

by

Yusuke HORIE*1, Yuta KAWAMURA*1, Akiyuki SEITA*2 and Mitsuho YAMADA*1

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Abstract

We have studied the relation between the various displays and the position error of Smooth pursuit eye movement (SPEM) while pursuing a rapidly moving target by increasing the number of experimental trials beyond that of the previous report. Focusing on CRT, EL, LCD and PDP, we showed the results of the position error of SPEM in each subject. Generally, as for the accuracy of SPEM to the speed change of the target, the same tendency was shown among displays which were used in this paper.

Keywords: smooth pursuit eye movement, frame rate, liquid crystal display (LCD), motion blur

1. INTRODUCTION

Recently, high-definition and large-size displays have become popular for home use. Moreover, the achievement of much higher-resolution displays by increasing the number of scanning lines, the improvement of the color reproducibility of the color filter and the speed-up of the frame rate are attracting attention. Specifically, for LCD, which has shown image quality degradation for high-speed moving images, a 120 Hz drive has become standard, and 240 Hz drive displays have also been developed. SPEM is said to be driven by the human brain to detect the speed of a moving object. We assumed that reproduction quality of a moving image on a display would influence the pursuing accuracy of SPEM. Whether or not we discern the deterioration of image quality when an image is moving speedily depends on whether or not we can follow the deteriorated part of the image with the fovea, which has the best eyesight. Therefore, we investigated the accuracy of SPEM as a measure to evaluate the display characteristics of various displays for high-speed moving images. We have reported that the response characteristics of the LCD influenced the accuracy of SPEM in the viewing of a rapidly moving image [1]. Moreover, we compared an LCD driven at 240 Hz with that driven at 120 Hz in terms of the accuracy of the SPEM [2]. From these experiments, we found that the SPEM varied according to the abilities of the individual subjects. Therefore, we increased the number of experiment trials and examined the differences among the subjects. Moreover, we added PDP, EL, and CRT in addition to LCD to our investigation. We found that the difference between the performance results of 120 Hz drive LCD and the 240 Hz drive LCD were not that different. We measured the response characteristics of the 120 Hz and 240 Hz LCD and reviewed the reasons. We found some differences between LCD and PDP at lower target speeds.

*1 Graduate school of Engineering, Tokai University
*2 East Japan railway Company

2. CHARACTERISTIC OF EYE MOVEMENT

In the oculomotor system, there are generally three kinds of eye movements, i.e. a small involuntary eye movement, a SPEM and a saccade. When one fixates at the stationary point on the image, our eye still moves randomly and continuously little by little. This eye movement is called a small involuntary eye movement. Among eye movements, the SPEM is said to be specifically driven by detecting the speed ingredient of a moving image. Saccade, an eye movement characterized by rapid, discontinuous movement, creates what has been called “saccadic suppression”, or the decline of object recognition during saccade; by contrast, the recognition during SPEM declines very little. When evaluating the image quality of the moving image, the characteristic of SPEM is considered to be an important factor. Here, we studied the accuracy of SPEM when pursuing a speedily moving target displayed on the various displays. We defined the position error between the eye position and the target position as the measure of the accuracy of SPEM when pursuing a speedily moving target. When we pursue the moving image, generally, a saccade occurs at first, and then SPEM succeeds. There is latency in the saccade, so that the saccade starts moving 160 - 200 ms later after the target movement. When the speed of the object is too fast for SPEM to pursue, saccades and SPEMs alternately occur as shown in Figure 1. One study found that the maximum speed of sustained SPEM was about 30 degrees/sec. Recently, it has been claimed that SPEM can pursue a moving image of at most 100 degrees/sec with a gain of about 0.9 (Gain is defined as the oculomotor speed / the object speed). When exceeding 100 deg/sec, the variance expands to the oculomotor speed, mainly to about 80 deg/sec.

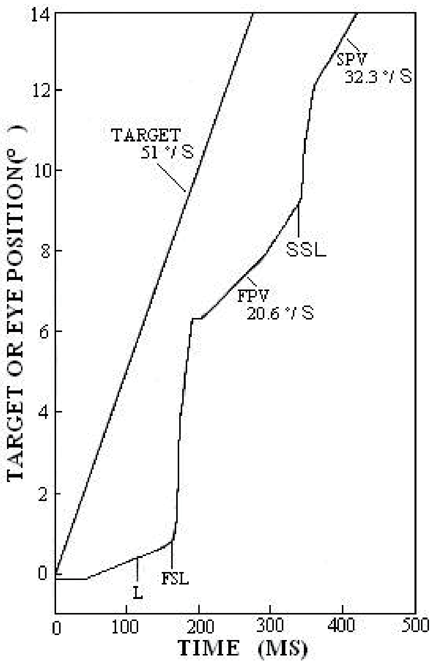

Figure 1.Characteristics of smooth pursuit eye movement [3]

3. CAUSE OF IMAGE QUALITY DEGRADATION FOR HIGH-SPEED MOVING IMAGES

Motion blur is one of the principal factors of the image quality degradation that occurs when a moving image is displayed by LCD. There are two factors involved. One is the fact that the LCD is a hold-type display. For such displays, the viewer moves his or her eyes continually along the moving image. The LCD keeps displaying the same image during one field, e.g. 1/60th of a second. On the human retina that is pursuing the moving image, the current image will overlap with the previous image. Therefore, a blur is observed in the boundary of the moving object and the background (Figure 2).

The second factor is the slowness of the response speed. In LCD, a white-color light source is provided from the backlight. The image is displayed when this light is passed through color filters that change the transmitted light into the three primary colors of RGB via a liquid crystal panel that controls the transmitted light volumes of each pixel. The liquid crystal panel changes the permeability of the light by the application of voltage to the liquid crystal molecules, controlling the direction of polarization. The response speed of this mechanism is slower than those of other displays.

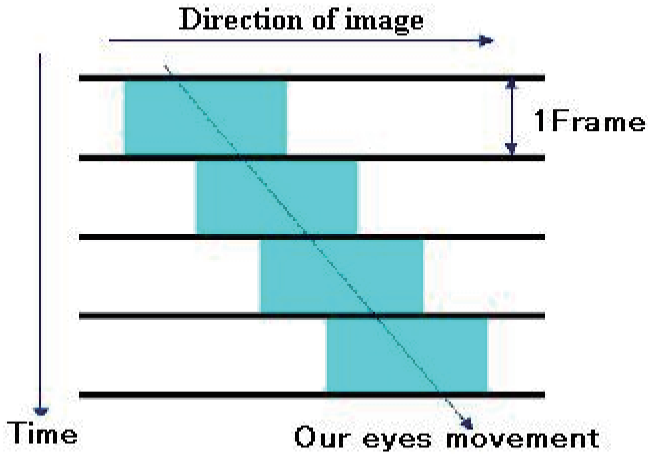

Figure 2.Display characteristic of a hold type

4.METHOD OF EXPERIMENT AND ANALYSIS

The experimental setup is shown in Figure 3.

A head-chin rest was used to immobilize the subject's head. The viewing angle of the display from the subject was 30 degrees, which is said to be the natural limit at which we can see an object only by eye movement. Exceeding these values, head movement was used as well as eye movement [4]. TKK 2930 of Takei & Co. (the scleral reflection method) was used to measure the eye movement. After the calibration of the eye movement, the experiment was started. First, a fixation point was displayed in the center of the display① and the subject was instructed to gaze at it in order to check the offset of the eye movement caused by the slip of the head movement. Next, after the fixation point was erased②, a fixation point for either the left or right was displayed③ to suggest to the subject the starting point of the moving target. The target moved from the direction④ where a fixation point was displayed at speeds of 5 deg/sec, 10 deg/sec, 20 deg/sec, or 30 deg/sec speed at random times (Figure 5). We made this one set and repeated 40 sets in all. A slit was cut in the center of the object of the cross-tip in order that the subject could pursue the target as correctly as possible. The subject was instructed to chase the target as faithfully as possible, and we measured eye movement. We defined the difference between the target position and the subject's eye position as the position error. We compared the position error to analyze the obtained results. Displays used in the experiment, their luminance during the experiment and their viewing distances are shown in Table 1~2. As the frame rates of EL and PDP, 60 Hz were used, since they were only available commercially up to now.

The subjects were three male students at our university who have normal eyesight, with a visual acuity of more than 1.0 (20 / 20) including corrected vision.

After the experiments, we drew a figure that showed the position of the eye along the vertical axis and the lapse of time along the abscissa at each session (Figure 6). From this figure, the data for times when the latency of the saccade, the saccade and blinking occurred and when the accuracy of SPEM degraded just before the target reached the end of the display were discarded.

Applying the above procedure, the difference between the target position and the subject's eye position during SPEM was estimated as mentioned before.

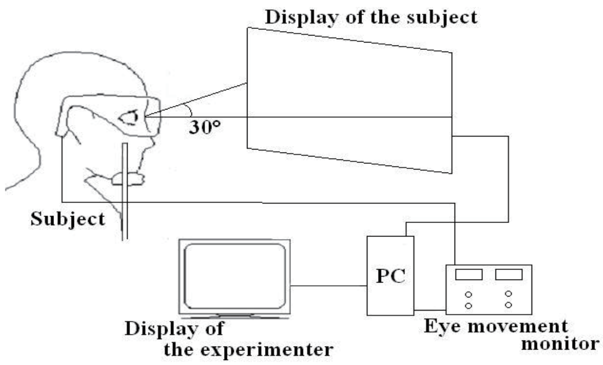

Figure 3. Environment of experiment

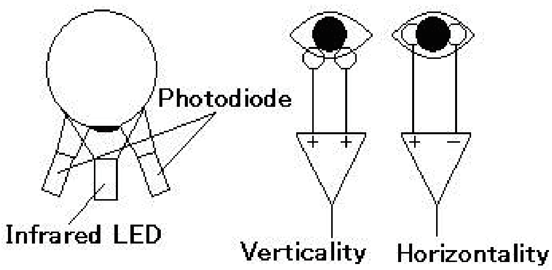

Figure 4. Scleral reflection method

Table 1. Display size and Viewing Distance

Display type	Display size	Distance
LCD(120 Hz)	40inch	112cm
LCD(240 Hz)	40inch	112cm
PDP(60 Hz)	37inch	120cm
CRT(60 Hz)	22inch	73cm
CRT(120Hz)	22inch	73cm
EL (60 Hz)	11inch	31cm

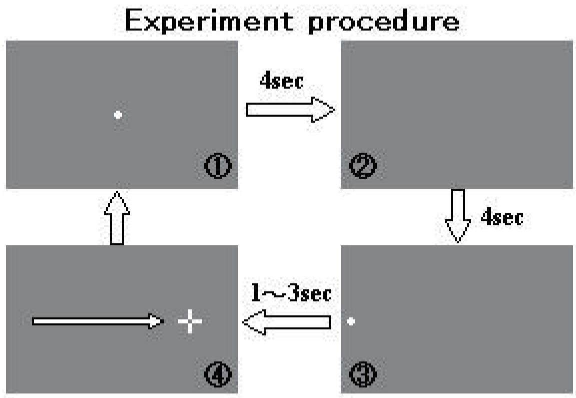

Figure 5 Experiment procedure

Table 2. Luminance of Target and Backgrounds

Display type	Target luminance	Background luminance
LCD(120 Hz)	157.6cd/m²	93.27cd/m²
LCD(240 Hz)	159.2cd/m²	94.94cd/m²
PDP (60 Hz)	67.85cd/m²	57.60cd/m²
CRT(60 Hz)	50.62cd/m²	27.74cd/m²
CRT(120 Hz)	49.86cd/m²	27.40cd/m²
EL (60 Hz)	68.42cd/m²	39.00cd/m²

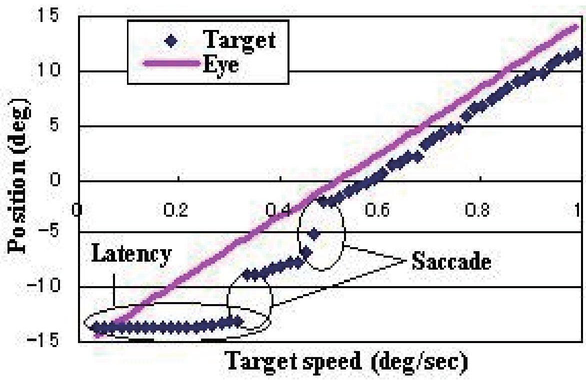

Figure 6. An Example of the data set during an experiment

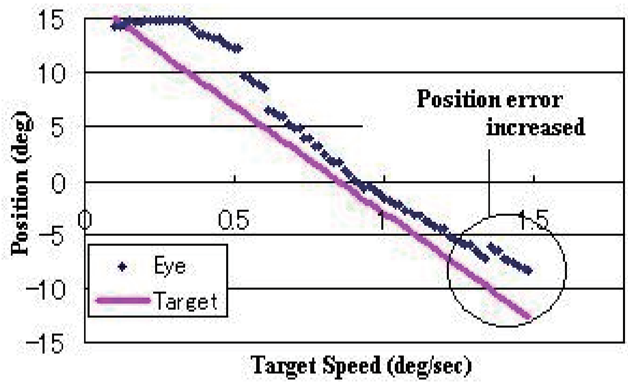

Figure 7. Example when the obtained data was discarded

5. RESULT

5.1 Results for CRT

The difference in the position error between 60 Hz and 120 Hz was small in subject 1. The position error for 120 Hz was smaller than that for 60 Hz in subject 2. The differences in the position error between 60 Hz and 120 Hz were small for the image speeds of less than 20 deg/sec in subject 3. However subject 3's position error for 60 Hz at 30 deg/sec was larger than that for 120 Hz. The position error increased according to the target speed in all subjects.

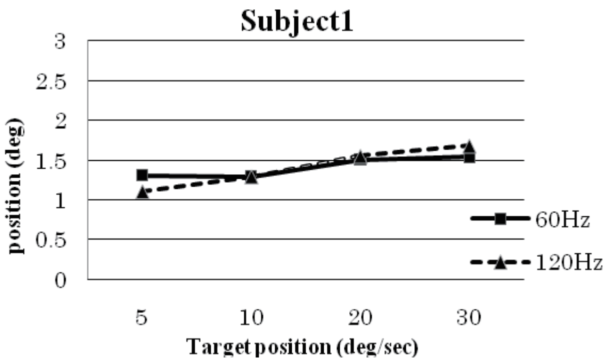

Figure 8. Results of CRT (Subject 1)

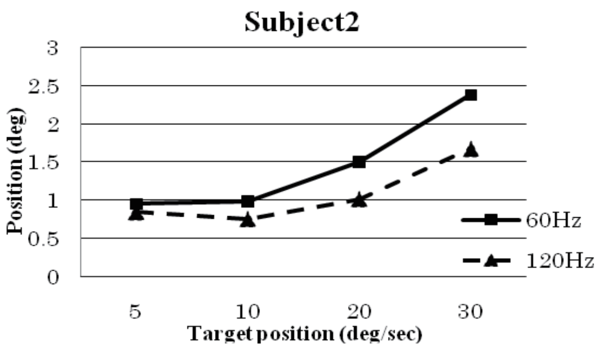

Figure 9. Results of CRT (Subject 2)

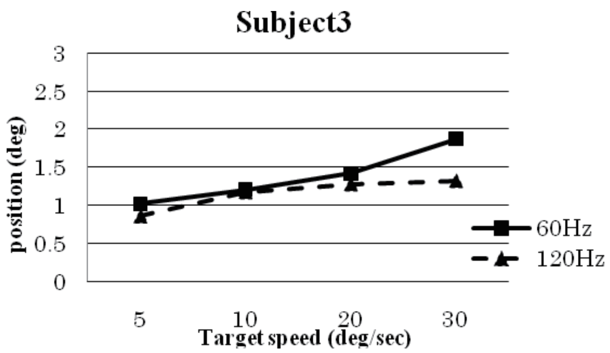

Figure 10. Results of CRT (Subject 3)

5.2 Results for EL

The variance of the position error was small among subjects. It increased according to the target speed, as with CRT.

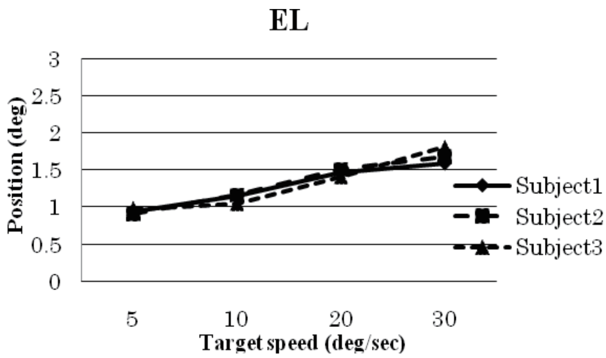

Figure 11. Results of EL

5.3 Results for LCD

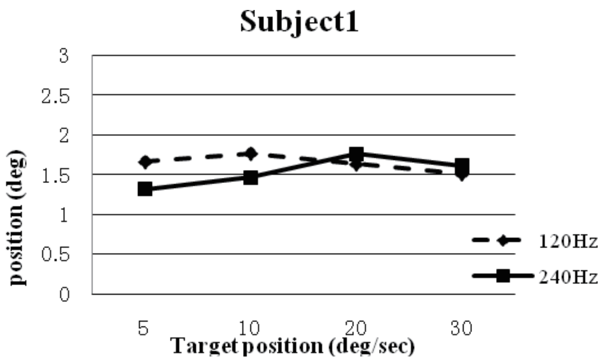

Figure 12. Results of LCD (Subject 1)

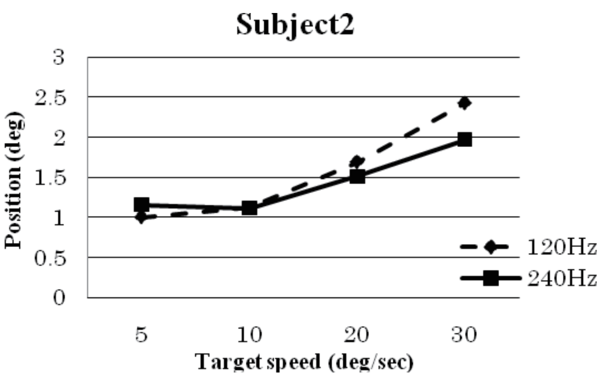

Figure 13. Results of LCD (Subject 2)

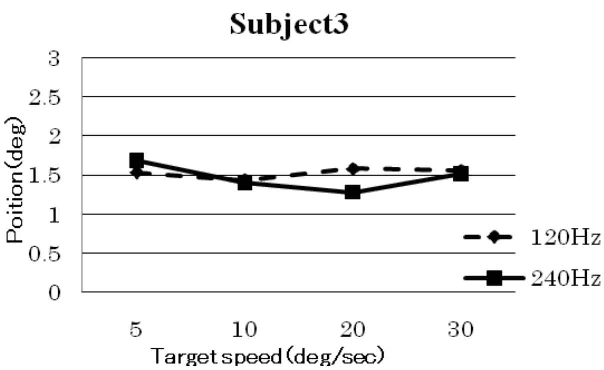

Figure 14. Results of LCD (Subject 3)

Figures 12, 13, and 14 show the results of the SPEM position error when viewers pursued a target on LCD. In each subject, the difference in position error between the 120 Hz and 240 Hz moving image was small. The position error increased with the target speed only in subject 2. In subject 2, the position error was larger than that of other subjects for a target moving at 30 deg/sec.

5.4 Results for PDP

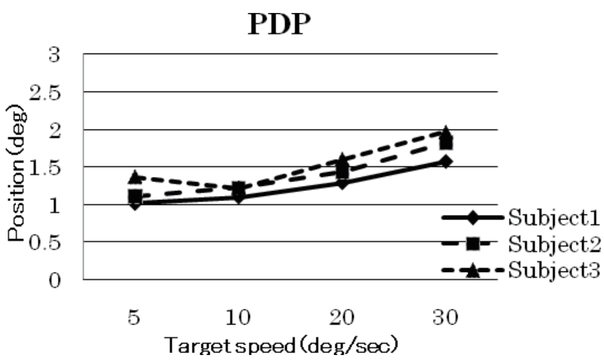

Figure 15. Results of PDP

The differences in the position errors by subject are shown in Figure 11. The difference among subjects is small. The position error increased according to the target speed.

5.5 Comparison of the results for LCD and PDP

The difference of the position error in each subject between LCD and PDP was small. The errors themselves tended to increase with the target speed. At 5 deg/sec-10 deg/sec, the position errors of LCD are equal to or slightly larger than PDP, depending on the subject. However, the position errors were almost the same and at most 1 deg-2 deg difference between the two displays for targets faster than 20 deg/sec.

6. DISCUSSION

6.1 CRT

As the reason why the distinctive difference of the position error did not appear in subject 1, it is considered that this subject was accustomed to the pursuing experiment because the experiment for CRT was executed last for this subject. Subject 2 might not be very good at pursuing an object moving as fast as 30 deg/sec, since the position error was larger than that of other subjects for both 60 Hz and 120 Hz moving images. In subject 3, little difference was observed for the movement less than 20 deg/sec, but the position error increased for that at 30 deg/sec and the influence of the refresh rate was seen.

6.2 EL

As with the other displays, the position error increased according to the target speed in all subjects, and the difference in position error between subjects was very small. This suggests that there was not a very large difference in the visibility of the moving image among subjects for EL.

6.3 LCD

The difference in position error between 120 Hz and 240 Hz was small in all subjects. This suggests that there is not a large difference in display characteristics at 120 Hz and 240 Hz. To clarify this result, we measured the display characteristics of LCD as depicted in 6.4.

6.4 Display methods of 120Hz and 240Hz

To investigate why the difference between the position errors for 120 Hz and 240 Hz was small, we measured the response characteristics of the LCD by the optical response time measurement tester T10 (Konika Minolta Holdings). Figure 16 shows an example of the response waveform for the LCD used in the experiment. As a result, it was clarified that both methods applied the same frequency to drive the LCD. Thus, it was suggested that LCD was also driven at 240 Hz in the case of the 120 Hz drive and that the same image might be continuously displayed every two frames as shown in figure 16. This could be one of the causes why little difference was observed in the accuracy of SPM while pursuing a moving target displayed at 120 Hz and at 240 Hz.

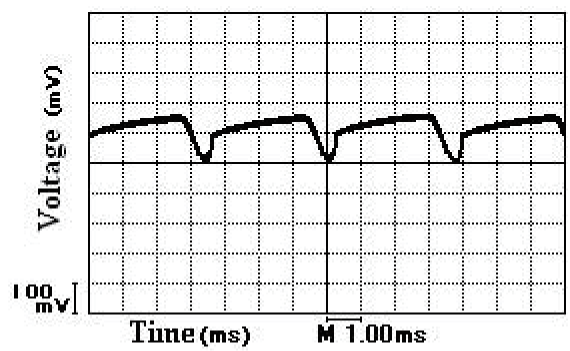

Figure 16. Example of the response waveform of the LCD used in the experiment

6.5 PDP

There were few differences among individuals viewing the PDP. A tendency for the position error of SPM to increase at target speeds above 10 deg/sec was observed.

6.6 Comparison of LCD and PDP

Since the position error above 20 deg/sec showed almost the same degrees in LCD and PDP, it was considered that the differences in the display methods had not produced conspicuous effects. However, at 5 deg/sec-10 deg/sec, the position error of LCD was equal to or larger than that of PDP. This result suggests that the difference in display methods between LCD and PDP may have influenced SPEM for slower image velocities.

7. SUMMARY

We have studied the relation between the various displays and the position error of SPEM while pursuing a rapidly moving target by increasing the number of experimental trials beyond that of the previous report. In this paper, focusing on CRT, EL, LCD and PDP, we showed the results of the position error of SPEM in each subject.

As a result of CRT, the difference of the frame rate did not influenceded in the accuracy of SPEM less than 10 deg/sec. But, the accuracyof SPEM tended to decline a little by the subject more than 20 deg/sec.

As a result of EL, the decline of the accuracy of SPEM was observed according to the increase of the target speed. Also, differences among the subjects are few.

Difference of the accuracy of SPEM was not observed between the results of 120Hz and those of 240 Hz in LCD. However, the decline of the accuracy of SPEM was also shown at the target speeds more than 20 deg/sec by the subject.

Generally, as for the accuracy of SPEM to the speed change of the target, the same tendency was shown among displays which were used in this paper.

In the future, we will analyze the influence on SPEM accuracy of targets slower than 10 deg/sec as well as those faster than 30 deg/sec. Moreover, we are planning to perform experiments changing the brightness of the targets and of the backgrounds. Here, we focused on eye movement while viewing a moving image. However, we also think it is important to compare subject evaluations regarding the recognition of image degradation with the results obtained above [6].

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