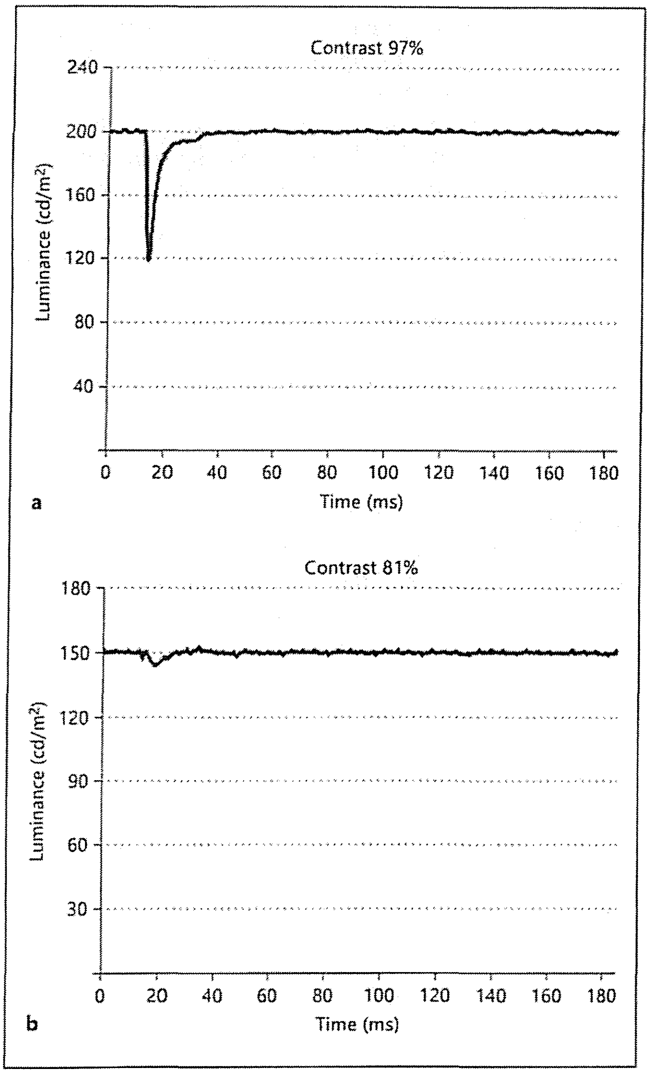

Fig. 2. Luminance changes of the 2-ms response LCD screen with a maximal contrast of 97% (**a**) and 81% (**b**). The LCD with 81% contrast showed a significant reduction in the change of total luminance during time (x-axis) compared with that with 97% contrast.

contrast was reduced to 81% on the LCD screen, ERGs were not elicited. This indicated that a flash VEP can be elicited with the contrast of the LCD monitor set at 97% but will not when the LCD monitor is set at 81% contrast.

Comparison of p-VEP Components between 5-ms and 2-ms Response LCD Screens

Reproducible VEPs were recorded using each monitor. The P100 amplitude and the N75 and P100 implicit times are plotted in figures 4a–c, respectively. When measuring the implicit time, the input lag of 1.2 ms for the

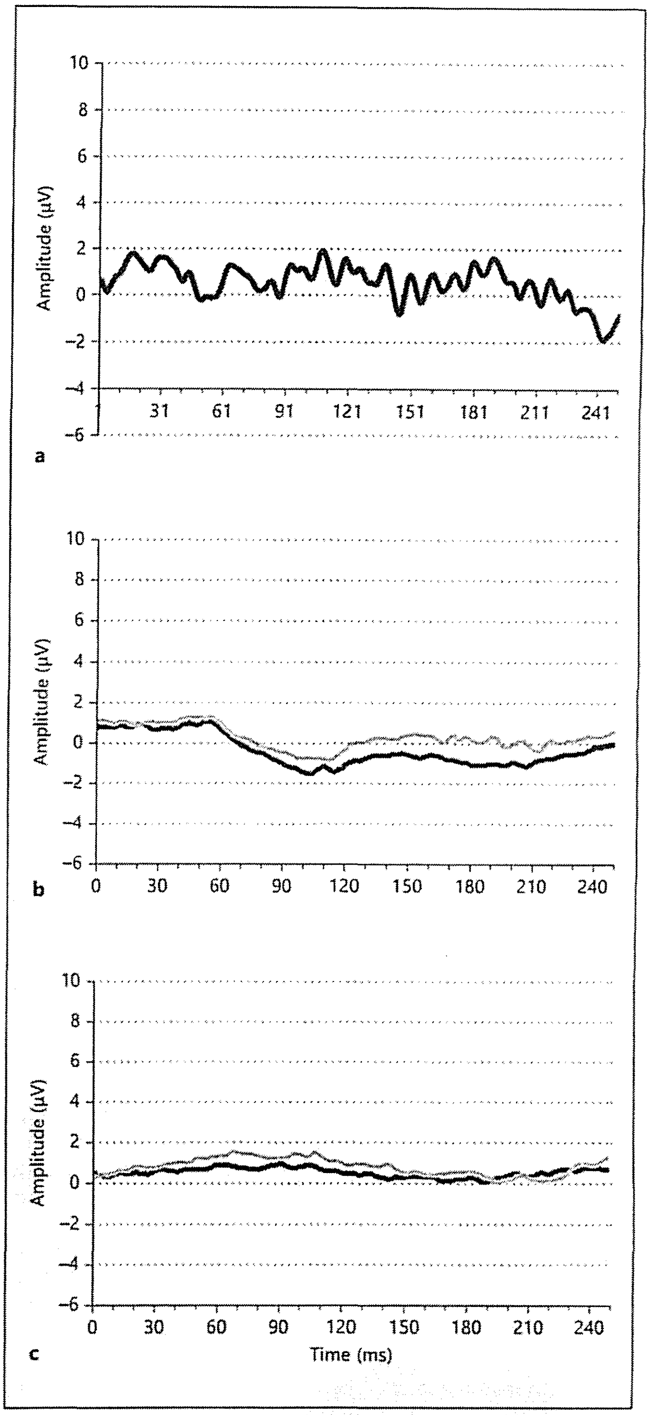

Fig. 3. ERGs elicited by placing a diffuser before each monitor screen. The ERGs elicited with the diffuser on the CRT monitor (**a**) were below the noise level whereas those with the 2-ms response LCD screen with 97% contrast for checkerboard stimulus (**b**) had a slow negative response. No ERG was recorded (**c**) when the 2-ms response LCD screen with 81% contrast checkerboard was covered by a diffuser.

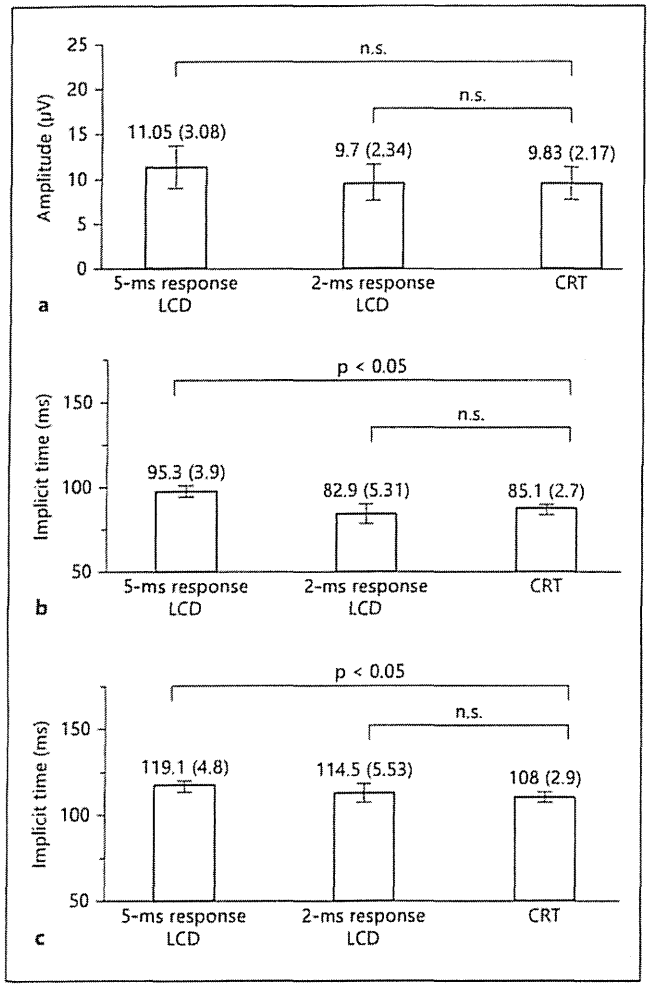

Fig. 4. Comparisons of each parameter between the p-VEPs elicited by CRT and by 5- and 2-ms response LCD screens. **a** No significant difference was found in the VEP P100 amplitude elicited either by the 5- or 2-ms response LCD screen to that elicited by the CRT screen. **b** The implicit time of N75 elicited by the 5-ms response LCD screen was significantly longer than that elicited by the CRT screen. No significant difference was observed in the implicit times of N75 between the p-VEPs elicited by the 2-ms response LCD screen and the CRT screen as a stimulator. **c** The implicit time of P100 elicited by the 5-ms response LCD screen was significantly longer than that elicited by the CRT screen, whereas no significant difference was observed between the implicit times of P100 between the p-VEPs elicited by the 2-ms response LCD screen and CRT screen. n.s. = Not significant.

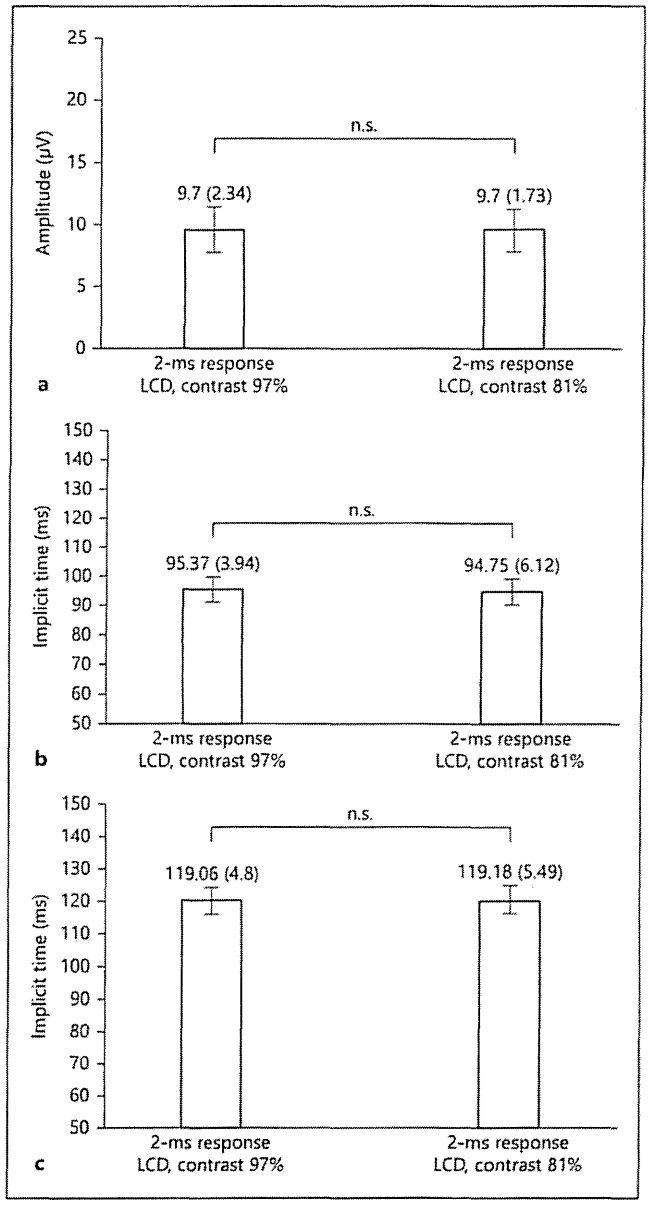

Fig. 5. Comparisons of each parameter of the p-VEPs elicited by a 2-ms response LCD screen with different contrasts of the checkerboard pattern. No significant difference was found in the VEP P100 amplitude (**a**), N75 implicit time (**b**) and P100 implicit time (**c**) elicited either by the 2-ms response LCD screen for contrasts of 97% (left) and 81% (right) of the checkerboard stimulus. n.s. = Not significant.

5-ms LCD display and 13.7 ms was subtracted from the measured times (see 'Luminance changes' above). The difference in the P100 amplitude between the responses was not significant. When compared to the VEPs recorded using the CRT display, the N75 and P100 implicit times were delayed in the VEPs elicited by the 5-ms response LCD screen. However, the N75 and P100 implicit times were not delayed with the 2-ms response LCD screens compared to those elicited by the CRT display.

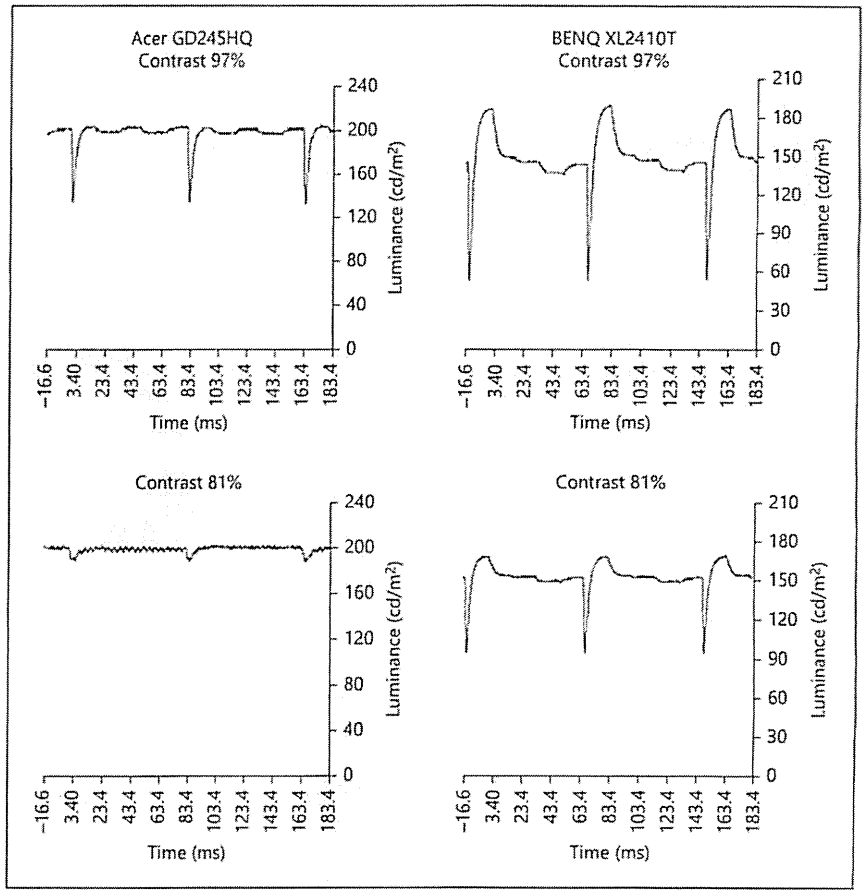

Fig. 6. Transient changes in the luminance in another 2-ms response LCD screen. The left column shows the luminance change of the 2-ms response LCD monitor used in this study (GD245HQbid, Acer) and the right column shows that in another 2-ms response LCD monitor (XL2410T, BENQ, Taipei, Taiwan). Note that the transient change was almost extinguished with the contrast of 81% in the left column whereas it was still marked even with the contrast of 81% in the right column.

Comparison of the p-VEP Waveforms Elicited by 2-ms Response LCD Screen with 97 and 81% Contrast

The P100 amplitude and the N75 and P100 implicit times of the p-VEPs elicited by the 2-ms response LCD display with 97 and 81% contrast are shown in figures 5a–c, respectively. No significant differences in the P100 amplitude, and the N75 and P100 implicit times between the responses with the different contrasts were found.

Discussion

The ISCEV standard for p-VEPs (2009 update) [7] states that the reversal of the black and white checks changes abruptly and repeatedly at a specified number of reversals per second. It also states that there must be no overall change in the luminance of the screen which requires that there be an equal number of light and dark elements in the display, and no transient luminance changes during the pattern reversal. At present, only CRT displays can meet these standards because LCD screens have an inherent time delay when the luminance reverses. For our experiments, we used a 5-ms and a 2-ms response LCD screen.

The effect of the response time on the implicit time has not been fully determined. The input lag and response time are specific to LCD screens, and it is important to compare the p-VEPs elicited by LCD displays to that elicited by CRT displays to normative data obtained from a control group.

Our earlier results showed that when the VEPs were elicited by a 5-ms response LCD screen, the implicit times of N75 and P100 were longer than that for VEPs elicited by a CRT screen. The delay is partly attributed to a transient change in the average luminance of the LCD monitor or the flash effect [6]. The flash effect can be minimized by decreasing the contrast of the checks, but the contrast must be reduced to 65% to completely remove the luminance artifact when using the 5-ms response LCD screen (17 inches, 340 × 270 mm, RDT233WX, Mit-

subishi, Tokyo, Japan). This lower contrast does not meet the ISCEV standard [6].

We hypothesized that using an LCD screen with shorter response time would minimize the flash effect. To test this hypothesis, we compared the p-VEPs elicited by a 2-ms response LCD screen to those elicited by a 5-ms response LCD. Our results showed that the implicit times of the p-VEPs elicited by the 2-ms response LCD screen were significantly shorter than that by the 5-ms response LCD screen (fig. 1), but ERGs could still be elicited when the 2-ms response LCD screen was covered with a diffuser (fig. 3).

Thus, we reduced the contrast of the checkerboard pattern to decrease the flash effect as we did for the 5-ms LCD display [6]. Our results showed that the flash effect was greatly reduced, and ERGs were not elicited with 81% contrast (fig. 2, 3). From these results, we conclude that a flash VEP can be eliminated by using a 2-ms response LCD screen with 81% contrast.

When comparing the p-VEPs elicited by the 2-ms response LCD screen to those elicited by the CRT, no significant difference was found in the amplitude of the P100 and the implicit times of N75 and P100 when the contrast of the 2-ms response LCD screen was set at 97 or 81% (fig. 5). These findings suggest that the 2-ms response LCD screen is a better substitute for the CRT screen as a stimulator for eliciting p-VEPs especially when the contrast was set at 81%.

However, the luminance change during the pattern reversal is different depending on the specifications of the LCD screen (fig. 6) as was the case for the LCD screens used in this study [6]. Thus, a reduction of the contrast may not eliminate the flash effect in all the commercial 2-ms response LCD displays. Further investigations on how to eliminate the flash effect are needed. Alternative ways might be using an organic electric-luminescence display to eliminate the flash effect.

In conclusion, the p-VEPs are affected by the flash effect and the input lag during the reversal phase when the checkerboard stimulus is generated on LCD screens. The flash effect can be reduced by using 2-ms response LCD screens and by reducing the contrast of the checkerboard pattern to approximately 81%. The p-VEPs elicited by such LCD displays are comparable to those elicited by conventional CRT screens.

Acknowledgment

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Disclosure Statement

No author has any financial or proprietary interest in any material or method mentioned.

H. Funada is an employee of Tomey Corp., Japan. Tomey Corp. had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript. All commercial identities mentioned in the manuscript were purchased by Teikyo University School of Medicine without receiving any financial gain. All authors have no additional competing interest that potentially influences the study, including financial relation.

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RESEARCH PAPER

Low luminance visual acuity in patients with central serous chorioretinopathy

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Background: The aim was to determine the low luminance visual acuity in eyes with central serous chorioretinopathy.

Methods: Seven eyes of seven patients with central serous chorioretinopathy and six eyes of six age-matched normal volunteers were examined. Low luminance visual acuity charts were created by an Apple Power Mac G5 computer and displayed on a cathode ray tube monitor (SONY GDM-F500). The background luminance was set at six different levels from 78.20 cd/m^2 to 0.37 cd/m^2. The visual acuities of the eyes with central serous chorioretinopathy at each of the six luminance levels were compared to those from their fellow eyes and to normal eyes.

Results: The mean visual acuities varied from 0.13, 0.23, 0.29, 0.42, 0.62 to 0.70 logMAR units as luminance varied from high to low. At the lowest luminance (0.37 cd/m^2), five of the seven eyes could not read any character. The mean visual acuities of the fellow eyes at the same luminance levels were 0.03, 0.06, 0.11, 0.20, 0.27 and 0.45 logMAR units and those of the normal volunteers were 0, 0.03, 0.08, 0.14, 0.23 and 0.38 logMAR units, respectively. The visual acuities of the eyes with central serous chorioretinopathy were significantly poorer than those of the normal eyes at all luminance levels except 0.37 cd/m^2 ($p < 0.05$ for all).

Conclusions: Although the eyes from all three groups had 0 logMAR units visual acuity under standard testing condition, the visual acuity of the eyes with central serous chorioretinopathy were significantly worse at low luminance levels. The low luminance visual acuity may provide information on the visual disturbances reported by central serous chorioretinopathy patients with 0 logMAR units visual acuity.

Key words: central serous chorioretinopathy, contrast sensitivity, low luminance visual acuity, optical coherence tomography, serous retinal detachment

Central serous chorioretinopathy (CSC) is characterised by a serous retinal detachment in the macular area. Central serous chorioretinopathy patients range in age from 20 to 50 years but most are middle-aged men. The central serous chorioretinopathy causes a central and paracentral relative scotoma in the visual field.[1–3] Although the visual acuity (VA) is relatively good, patients often complain of difficulty with visual activities performed in the evening and at night under low ambient illumination. In conventional VA tests, such visual disturbances are usually not detected because the backgrounds of VA testing charts have high luminance.

To evaluate patients with central serous chorioretinopathy and visual disturbances

under low luminance conditions, we need to measure the VA using test charts with low background luminance. It is well known that VA is affected by the degree of ambient luminance and Shaler[1] reported that the VA of normal eyes decreased under low luminance conditions. Because patients with good VA can have depressed visual function, for example, decreased contrast sensitivity, poorer colour discrimination, reduced focal macular electroretinogram (ERG), reduced focal retinal sensitivity and visual field defects,[5–12] it might be expected that patients with central serous chorioretinopathy would also have decreased VA under low luminance. There have been no studies focusing on low luminance VA in patients with central serous chorioretinopathy.

The purpose of this study was to determine the VA of patients with central serous chorioretinopathy under low luminance conditions. To accomplish this, we made a computer program to create low luminance visual acuity charts and determined the VA under six different background luminance levels in seven patients with central serous chorioretinopathy.

METHODS

Seven eyes of seven patients with central serous chorioretinopathy and six eyes of six age-matched healthy control subjects were tested. The inclusion criteria were:

1. presence of subretinal fluid (serous retinal detachment: SRD) involving the fovea in the optical coherence tomographic (OCT) images
2. unilateral central serous chorioretinopathy with the fellow eye normal and
3. visual acuity of 0 logMAR or better in both eyes.

The exclusion criteria were:

1. evidence of choroidal neovascularisation in the fluorescein angiographic (FA) and indocyanine green angiographic images and
2. the presence of other ocular or macular diseases.

Patients with central serous chorioretinopathy, who had received laser photocoagulation were also excluded.

The diagnosis of central serous chorioretinopathy was based on the presence of a serous retinal detachment documented by leakage from the retinal pigment epithelium in the fluorescein angiographic images. The VA was measured with a Landolt C chart using standard retroillumination with a luminance of 220 cd/m^2. We also examined six eyes of six normal volunteers with the same testing protocol. The OCT examination was carried out with either a Heidelberg Spectralis OCT (Heidelberg Engineering, Heidelberg, Germany) or with a Stratus OCT 3000 (Carl Zeiss Meditec, Inc, Dublin, CA, USA). The height of the serous retinal detachment (SRDH), the width of the serous retinal detachment (SRDW) and the thickness of sensory retina (foveal thickness: FT) were manually measured in the horizontal cross-sectional OCT images, which included the fovea (Figure 1). These measurements were made by one of the authors (KS), who had no information about the patients. The values of these parameters were used for statistical analyses.

The procedures used in this study conformed to the tenets of the Declaration of Helsinki. An informed consent was obtained from all subjects. Approval to conduct this study was obtained from the Institutional Review Board of Surugadai Nihon University Hospital, Tokyo, Japan.

Low luminance visual acuity charts and procedures

Low luminance VA charts were created with an Apple PowerMac G5 computer and displayed on a monitor (SONY GDM-F500). Landolt Cs were used for the characters and they followed the design rule of the Early Treatment Diabetic Retinopathy Study charts (Figure 2). Six levels of background luminance were used, namely, 78.20 cd/m^2, 31.87 cd/m^2, 11.37 cd/m^2, 4.14 cd/m^2, 1.30 cd/m^2 and 0.37 cd/m^2. The luminance of the Landolt C rings was kept as close to zero cd/m^2 as possible and the contrast for all conditions approached 100 per cent.

Identification of the largest Landolt C at the distance of 308 cm represented a VA of 0.7 logMAR units. The ring size was reduced in steps of 0.1 to -0.4 logMAR units. The tests were conducted from the lowest luminance level in a dark room after waiting seven minutes for dark adaptation.

Analyses

We compared the VA of the eyes with central serous chorioretinopathy with that of the fellow eyes and that of normal eyes at each luminance level. To determine the statistical significance of any differences, Student's t-tests were used. The VA in logMAR units was plotted on the ordinate for the different luminance levels on the abscissa. The data were fit to a linear equation as:

$$y = a \times x + b,$$

where 'y' is the logMAR VA and 'x' is the luminance expressed in logarithmic units. 'a' is the steepness of the best-fitted line and represents how much the VA is altered by a step change in the background luminance.

Thus, a large 'a' value means that the VA would be greatly changed by a step change in the background luminance. 'b' is the logMAR VA at very low or no background luminance, that is, when 'x' is zero. This is the point where the regression line intersects the ordinate of the logMAR VA line (Figure 1). The difference in the slopes for central serous chorioretinopathy, fellow and normal eyes were tested for significance by assessing the interaction term between background luminance and eye type using an analysis of covariance (ANCOVA) technique.

The correlations between the parameters of the OCT images and the constants 'a' and 'b' were determined by the Spearmann coefficients of correlation. The Bonferroni correlation was used to avoid type I error. The statistical significance was set at 0.01 for the t-tests because there were five comparisons and at 0.17 for the ANCOVA because there were three comparisons.

RESULTS

The patients with central serous chorioretinopathy included five men and two women and the mean and standard deviation of their ages was 41.3 ± 3.9 years (range 39–50 years). The duration of the

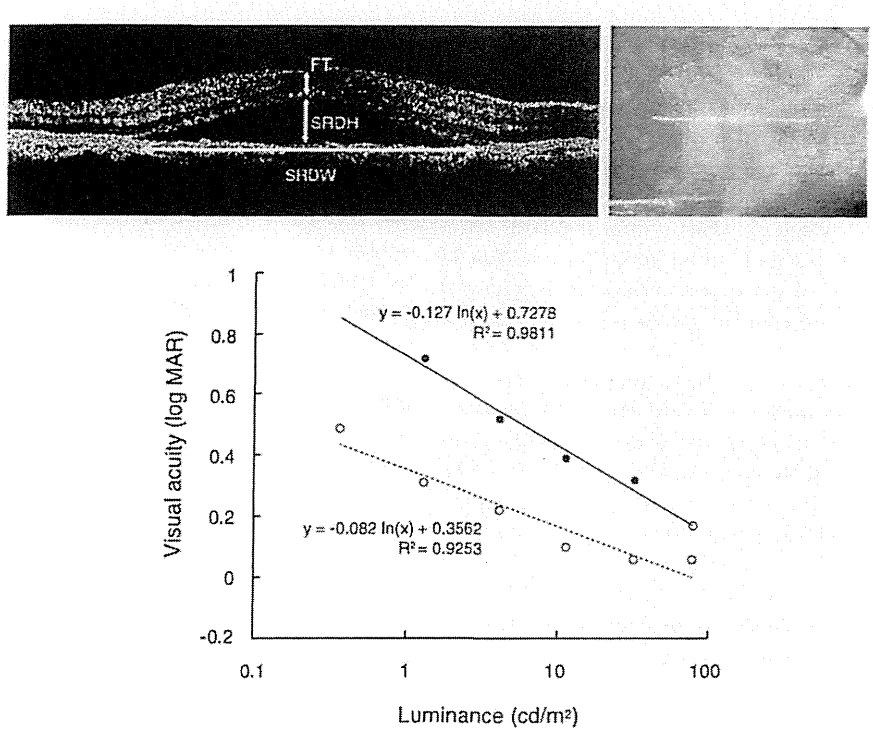

Figure 1. Optical coherence tomographic (OCT) image and infrared fundus photograph; also shown in a graph relating the visual acuity in logMAR units to the background luminance in eyes with central serous chorioretinopathy (CSC). The serous retinal detachment height (SRDH) was taken to be the distance between the outer segment/inner segment (IS/OS) line of the photoreceptors and the anterior surface of the retinal pigment epithelium/Bruch membrane. The width of the serous retinal detachment (SRDW) was taken to be the width of the serous retinal detachment in the OCT images and the foveal thickness was the distance between the internal limiting membrane (ILM) and IS/OS line. In cases where the IS/OS line was not clear, the basal edge of the hyper-reflective band representing the detached sensory retina was used.
Top left: Horizontal cross-sectional optical coherence tomographic (OCT) image including the fovea in an eye with central serous chorioretinopathy (Case 5). The cross-section corresponds to the horizontal line indicated in the right side of the fundus photograph. The serous retinal detachment height (SRDH), width of the serous retinal detachment (SRDW) and the foveal thickness (FT) are shown.
Top right: Infrared fundus photograph indicating the cross line of the left-side OCT image.
Bottom: Relationship between logMAR visual acuity (VA) and background luminance in Case 5. The logMAR VA was linearly correlated with the luminance. The logMAR VA of the central serous chorioretinopathy-affected eye was higher than that of the healthy fellow eye at each luminance level. ●: affected eye, ○: healthy fellow eye. The fitted line and the formula are shown as well.

symptoms was 1.0–1.5 months (Table 1). The mean ages of the normal volunteers was 38 ± 9 years (range 22–47 years). The mean VAs of the central serous chorioretinopathy and fellow eyes at each luminance are shown in Table 1. At the lowest luminance level of 0.37 cd/m^2, five of seven patients could not correctly identify any of the targets using the eye with central serous chorioretinopathy. The mean VAs of the normal volunteers were 0 ± 0.05, 0.03 ± 0.04, 0.07 ± 0.06, 0.14 ± 0.06, 0.23 ± 0.11 and 0.38 ± 0.11 logMAR units, respectively.

The VA in logMAR units is plotted against the background log luminance in Figure 3. The VA of the eyes with central serous chorioretinopathy was significantly poorer than that of normal eyes at all luminances except 0.37 cd/m^2 and 78.20 cd/m^2 ($p < 0.01$ for all). The VA of the eyes with central serous chorioretinopathy was significantly poorer than that of fellow eyes at all luminances except 0.37 cd/m^2 and 78.20 cd/m^2 ($p < 0.01$ for all). No significant differences were found among the central serous chorioretinopathy, fellow and volunteer eyes in the slopes of the fitted linear function by ANCOVA.

The constants, 'a' and 'b' and the coefficient of regression (R^2) are shown in Table 2. There was no significant correlation between any OCT parameters and 'a' (slope) or 'b' (intercept).

DISCUSSION

Patients with central serous chorioretinopathy have a relatively central scotoma, metamorphopsia, micropsia, colour vision abnormalities and visual disturbances under low luminance despite the relatively good standard VA. Studies on the relationship between the luminance of the VA charts and VA in eyes with central serous chorioretinopathy have not been reported. Patients with central serous chorioretinopathy often complain of difficulty in reading during the evening and night, that is, at low luminance levels. The VA obtained by conventional acuity charts is not a good measure for predicting how these patients will perform in low luminance environments.

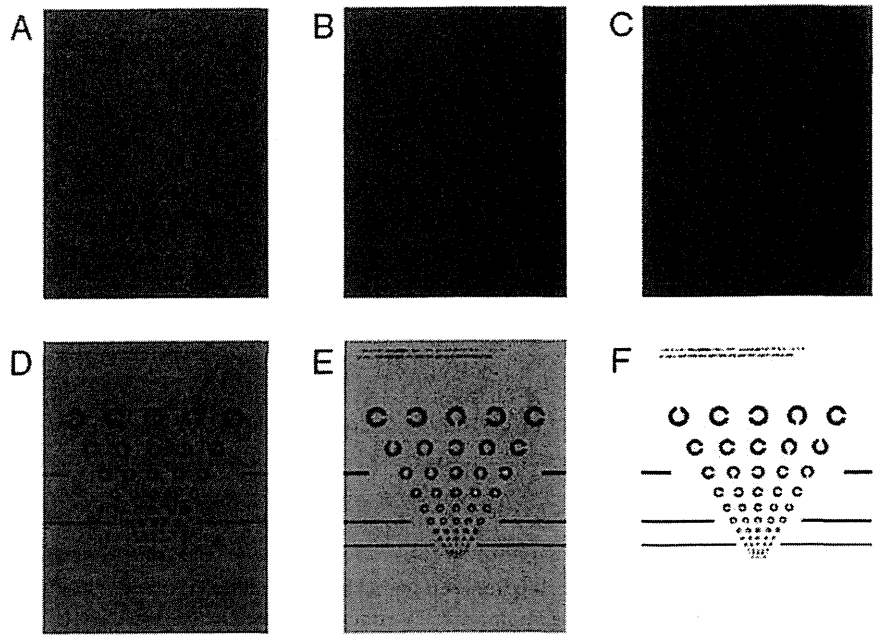

Figure 2. Low luminance visual acuity charts. The background luminance values were (A) 0.37 cd/m^2, (B) 1.30 cd/m^2, (C) 4.14 cd/m^2, (D) 11.37 cd/m^2, (E) 31.87 cd/m^2 and (F) 78.20 cd/m^2. Low luminance charts are difficult to reproduce in print.

Table 1. Visual acuities under different background luminances in patients with central serous chorioretinopaty

Patient no.	Age (years)	Gender	Affected eye						Fellow eye					
			78.20 cd/m^2	31.87 cd/m^2	11.37 cd/m^2	4.14 cd/m^2	1.30 cd/m^2	0.37 cd/m^2	78.20 cd/m^2	31.87 cd/m^2	11.37 cd/m^2	4.14 cd/m^2	1.30 cd/m^2	0.37 cd/m^2
1	39	M	0.01	0.12	0.15	0.27	0.55	N.R.	-0.04	0	0	0.03	0.13	0.35
2	41	F	0.16	0.16	0.24	0.3	0.46	0.64	0.03	0.06	0.12	0.17	0.34	0.45
3	50	F	0.16	0.28	0.31	0.5	0.65	N.R.	0.1	0.22	0.31	0.4	0.42	0.55
4	41	M	0.13	0.29	0.3	0.41	0.58	0.76	0.03	0.02	0.07	0.17	0.18	0.45
5	40	M	0.17	0.32	0.39	0.52	0.72	N.R.	0.06	0.06	0.1	0.22	0.31	0.49
6	39	M	0.15	0.23	0.26	0.37	0.59	N.R.	0.04	0.07	0.1	0.24	0.35	0.5
7	39	M	0.1	0.22	0.36	0.6	0.76	N.R.	0.01	0	0.1	0.2	0.29	0.36

Visual acuities are shown as logMAR. M: male, F: female, N.R.: not recordable

Table 2. Parameters of the optical coherence tomographic image and fitting of low luminance visual acuity in eyes with central serous chorioretinopathy

Case	Age	Gender	OCT parameter (μm)			Low luminance visual acuity			
			FT	SRDH	SRDW	a	b	R^2	p
1	39	M	183.3	275.0	2703.1	-0.121	0.5098	0.9079	0.0122
2	41	F	216.7	141.7	1171.9	-0.091	0.4932	0.9292	0.0193
3	50	F	244.1	141.1	2458.2	-0.118	0.6607	0.9636	0.0030
4	41	M	180.7	231.4	3004.7	-0.111	0.6143	0.9648	0.0005
5	40	M	191.7	308.3	2745.0	-0.127	0.7278	0.9811	0.0011
6	39	M	183.1	404.3	4086.0	-0.101	0.5603	0.9171	0.0104
7	39	M	181.2	322.1	3239.9	-0.166	0.8049	0.9894	0.0005

M: male, F: female, OCT: optical coherence tomography, these parameters are indicated in Figure 1.
FT: foveal thickness, SRDH: height of the serous retinal detachment, SRDW: width of serous retinal detachment. When low luminance visual acuity was plotted against background luminance as shown in Figure 1, the following formula was fitted: $y = a \times x + b$, when y indicates logMAR and x indicates log(luminance), R^2: coefficient of regression

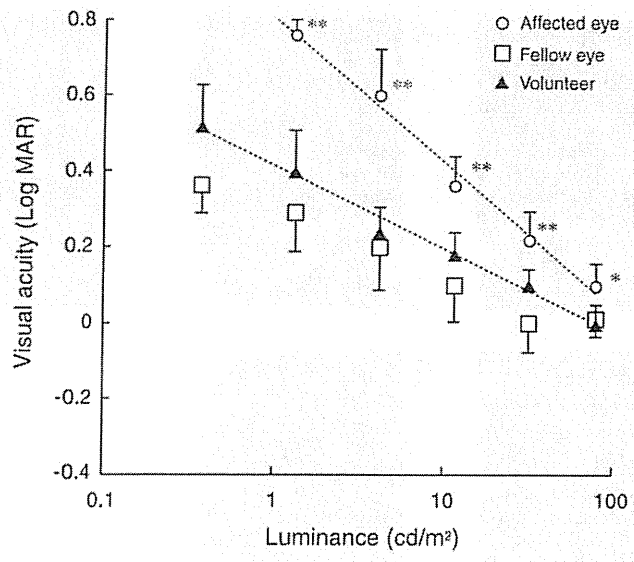

Figure 3. Relationship between logMAR visual acuity (VA) and the log background luminance. The data were fitted by the least square method and a linear equation between the logMAR VA and log luminance for the three groups. The logMAR VA is linearly correlated with the luminance. The logMAR VA of the eye with central serous chorioretinopathy is significantly higher than that of the fellow eye at each luminance level. Visual acuities at all levels of luminance except 0.37cd/m² are significantly different between central serous chorioretinopathy and the eyes of normal volunteers (*$p < 0.05$, **$p < 0.01$). ○: affected eye, □: fellow eye, ▲: normal eye of control participants, error bars indicate standard deviation.

Thus, we developed a computer program which allowed us to create Landolt Cs on a computer monitor screen with different background luminances. With these targets and background luminances, we were able to evaluate how luminance levels affected the VA in central serous chorioretinopathy patients.

Shlaer[4] reported that lower background luminances led to lower VA in normal eyes and we obtained similar results in our normal eyes. The VA of eyes with central serous chorioretinopathy also decreased according to the decrease in background luminance but the deterioration was more severe than that of normal eyes at all background luminance levels. We found that VA in logMAR units was linearly correlated with the logarithm of the background luminance. The logMAR VA in eyes with central serous chorioretinopathy was significantly higher, that is, poorer VA, than that in normal control eyes.

Hypotheses have been presented to explain the decreased VA under low luminance in normal eyes.[13,14] Thus, Hecht[13] suggested that the number of cone photoreceptors activated is decreased at low luminances. Our subjects were dark-adapted for seven minutes before testing and the cone system was expected to be functioning during this period in a healthy retina, and all of the normal fellow eyes could see at the lowest background luminance. Five of seven eyes with central serous chorioretinopathy could not identify even one Landolt C at the lowest luminance level, although the VA measured under standard conditions was at least 0 logMAR units in all eyes. These findings suggest that the foveal cones are not functioning normally in low light conditions in eyes with central serous chorioretinopathy.

Chuang and colleagues[15] reported that the rods were more affected than cones in eyes with central serous chorioretinopathy; however, they did not evaluate the rods selectively to determine whether the cones were indeed normal. The decreased VA measured under mesopic conditions in our study is probably due to impairments of both cone and rod function. This is consistent with the results of the Humphrey perimetric retinal sensitivity decrease in the detached area in eyes with central serous chorioretinopathy.[9]

Recent advances in OCT have provided some correlations of the foveal microstructure with visual function in several retinal diseases.[9,16–19] Sekine, Imasawa and Iijima[9] reported that the thickness of the serous retinal detachment and not neurosensory retinal thickness, was significantly correlated with visual sensitivity measured by automated static perimetry in eyes with central serous chorioretinopathy. It was also reported that the initial VA was significantly worse in eyes with a higher serous retinal detachment in Vogt-Koyanagi-Harada disease but it was not significantly correlated with foveal thickness.[17] Therefore, we anticipated the possibility that some morphological parameters might be correlated with low luminance VA but this was not the case. Many factors such as the patient's age, duration of central serous chorioretinopathy, size of the detached area, central cone function and arrangement of cone and rod cells, may have influenced the low luminance VA.

There are some limitations of this study. The small sample might have limited the statistical power of our anlayses. Further investigation on the relationship between microstructural changes and low luminance VA would be helpful for understanding the pathologic mechanism of patients' complaints under reduced luminance conditions.

Studies of cases of unilateral central serous chorioretinopathy have shown that

the fellow eyes can have subclinical central serous chorioretinopathy. The studies of Maaranen, Tuppurainan and Mäntyjärvi[20] and Baran, Gürlü and Esgin[21] support this suggestion because they found a high percentage of colour deficiency in the fellow eyes of patients with central serous chorioretinopathy. Baran, Gürlü and Esgin[21] also observed that contrast sensitivity was reduced in the fellow eyes of patients with unilateral central serous chorioretinopathy. Iida and colleagues[22] reported choroidal vascular abnormalities in indocyanine green angiographic images in the unaffected fellow eye. In our study, the VA of fellow eyes was not significantly different from that of age-matched normal eyes. Further studies are needed to assess the visual status of fellow eyes.

In conclusion, the VA of eyes with central serous chorioretinopathy was significantly more depressed at low background luminances than normal eyes. Low background luminance VA testing is useful for evaluating visual disturbances at low ambient luminance experienced by patients with central serous chorioretinopathy. There is a potential use here as one of the functional parameters in evaluating and flagging of central serous chorioretinopathy or therapeutic effect of new therapies such as photodynamic therapy.

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ORIGINAL RESEARCH ARTICLE

Liquid crystal display screens as stimulators for visually evoked potentials: flash effect due to delay in luminance changes

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Abstract
Purpose The cathode-ray tube (CRT) screen has recently been replaced by liquid crystal display (LCD) screens as visual stimulators for pattern-reversal visually evoked potentials (p-VEPs). The aim of the study was to evaluate the usefulness of LCD screen to elicit p-VEPs.
Methods The waveforms of the p-VEPs elicited by a LCD panel were compared with those elicited by a conventional CRT screen. The changes in the luminance of each screen were measured with a photodiode, and the mean luminance change was measured with a luminance meter. VEPs and electroretinograms (ERGs) were also recorded when the monitor was covered by a diffuser.
Results The p-VEPs elicited by the LCD consisted of the N75 and P100 components of the conventional VEPs and had good reproducibility. The average latency of these components was significantly delayed by 9.8 ms for N75 and 10.2 ms for P100, and the N75-P100 amplitude was significantly larger than the conventional p-VEP elicited by the CRT screen. During the reversal phase, especially from black-to-white, the luminance of the LCD screen was transiently reduced, and it elicited a flash VEP and ERG. A reduction in the contrast of the checks minimized the transient change in the luminance, and the VEP waveform was more similar to that elicited by the CRT screen.
Conclusions The results suggest that when an LCD monitor is used as an alternative visual stimulator to elicit p-VEPs, the delay in the luminance change and the flash effect needs to be taken into account.

Keywords Liquid crystal display monitor · Visually evoked potentials · Cathode-ray tube · Flash visually evoked potentials · Pattern-reversal visually evoked potentials · Contrast

Introduction

Most electrophysiological laboratories use cathode-ray tubes (CRTs) on which various types of stimuli can be generated, for example, checkerboard patterns to elicit pattern-reversal visual evoked potentials (p-VEPs). However, the CRT has recently been replaced by liquid crystal display (LCD) screens, and more and more manufacturers of VEP instruments have been selected to use LCD screens as visual stimulators. In the International Society for Clinical Electrophysiology of Vision (ISCEV) standard for clinical visual evoked potentials (2009 update) [1], the type of optimal stimulator was not mentioned.

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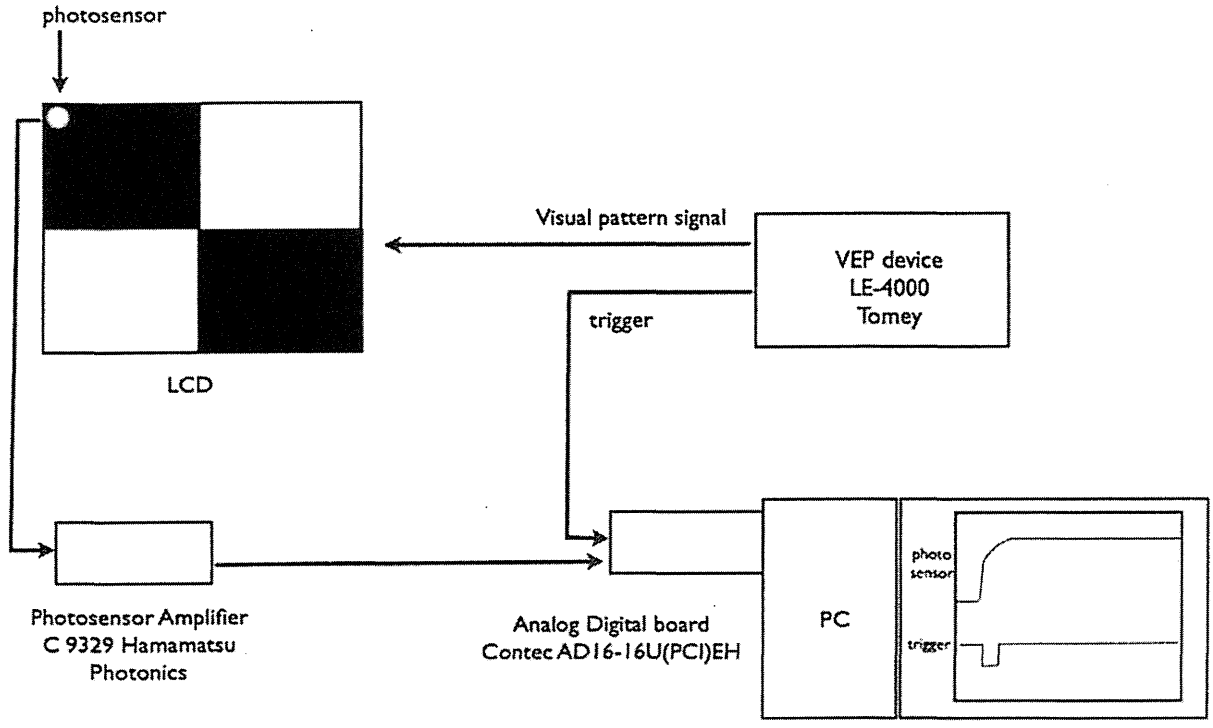

Fig. 1 System used for measuring the luminance changes of a single check

The LCD has an inherent difficulty in increasing the luminance rapidly because it takes several milliseconds for the crystal molecules to become aligned to permit light to pass through the polarizing filter of the LCD screen (http://www.sharp.co.jp/products/lcd/tech/s2_1.html, Fig. 1) [2, 3]. Some investigators [4–6] and our earlier results [7] found that the latency of the VEPs elicited by LCD screens was longer than that with CRT screens. The delay was believed to be related to the total temporal differences between the signal input to the LCD and radiometric output that is caused by both the response time and the input lag. It is well known [7] that the time course of the luminance change of the LCD screen was not symmetrical when switching from black-to-white and from white-to-black. This produced a transient change in the mean luminance of the entire display which could possibly elicit a flash VEP. This prompted us to evaluate this unwanted transient change in luminance and to minimize the flash VEP component by reducing the contrast luminance of the checkerboard pattern.

The purpose of this study was to determine the luminance changes of the LCD as a stimulator for eliciting p-VEPs and to investigate potential artifacts when an LCD screen is used to elicit p-VEPs.

Subjects and methods

Subjects

p-VEPs were recorded from 29 eyes of 29 healthy volunteers who did not have any ocular diseases except for refractive errors. There were 10 men and 19 women, and their mean ± standard deviation age was 24.2 ± 6.5 years with a range from 21 to 46 years. The procedures used conformed to the tenets of the Declaration of Helsinki. The study was a prospective study with approval of the Ethics Committee of the Teikyo University (Study ID Number: 10-075). Informed consent was obtained from all participants to participate in the research.

p-VEP recordings

Subjects were preadapted to the room lighting, and all recordings were performed under room lights with a illuminance of about 104 lux. A small black fixation point was positioned at one corner of four checks in the center of the stimulus display, and the subjects were instructed to fixate the point and to try not to blink. The

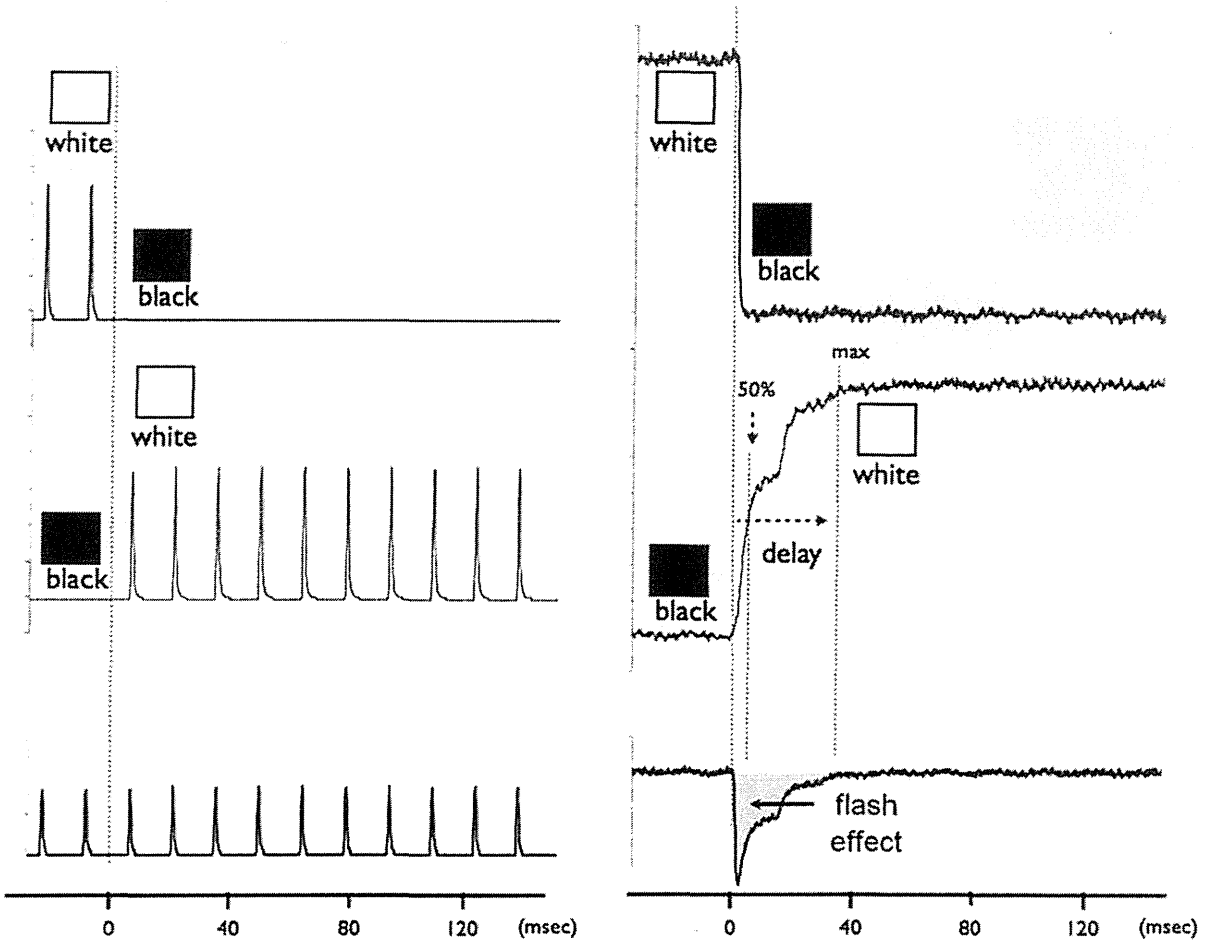

Fig. 2 Luminance changes of cathode-ray tube (CRT) screen in *left column* and conventional 60 Hz liquid crystal display (LCD) screen in the *right column*. In both columns, the *top figure* shows the changes of the checkerboard luminance from white-to-black; the *middle figure* shows the changes in luminance from black-to-white; and the *bottom figure* shows a simulation of the average of the reversal pattern luminance of a single check. It does not show the real luminance change in a single check. Because half of the checks are changing in the opposite direction, the bottom figure represents luminance change of entire screen. Note that, in the CRT screen (*left side*), there is no change in the total luminance (*y* axis) during time (*x* axis). On the other hand, the conventional LCD screen (*right side*) has an abrupt change of the luminance (*y* axis) at the time of reversal change of the checkerboard (*x* axis)

subjects wore their best refractive correction, and all recordings were monocular.

The recording electrode was placed 2.0 cm superior to the inion (Oz), and the reference electrode was placed on Fz. The ground electrode was placed on the earlobe. Signals were amplified 4,000 times with an amplifier (LE-4000, Tomey Corporation, Nagoya, Japan), and the band pass filters were set at 1.0–100 Hz. The sampling rate was 1.0 kHz, and 128 responses were averaged.

The recordings were performed at least two times to confirm the reproducibility. In addition, the measurements for each subject were performed two times with a 1 week interval to determine the inter-measurement variability.

Measurements of luminance of single check

To determine the time course of the luminance changes, the luminance of one check was measured with a photodiode (S1133, Hamamatsu Photonics Co. Ltd, Hamamatsu, Japan) attached to the upper left corner (Fig. 1). The luminance was also measured at the 4 corners and at the center of the screen with a luminance meter (CA-100S, Konica Minolta, Inc.,

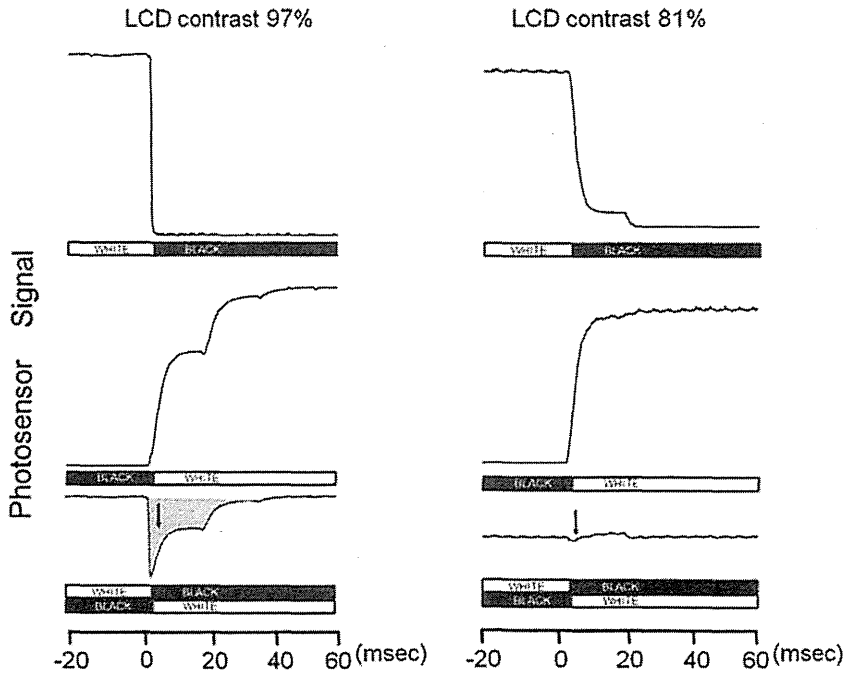

Fig. 3 Luminance changes of liquid crystal display (LCD) screen with a maximal contrast of 97 % in the *left column* and 81 % contrast in the *right column*. In both *columns*; the *top figure* shows the changes of the checkerboard luminance from white-to-black; the *middle figure* shows from black-to-white; and the *bottom* signal shows the averaging of the reversal pattern luminance of a single checkerboard. Note that, for the LCD with 81 % contrast (*bottom right column*), there is a considerable reduction in the change of total luminance (*arrow*) during time (*x* axis) compared with 97 % contrast (*bottom left column*)

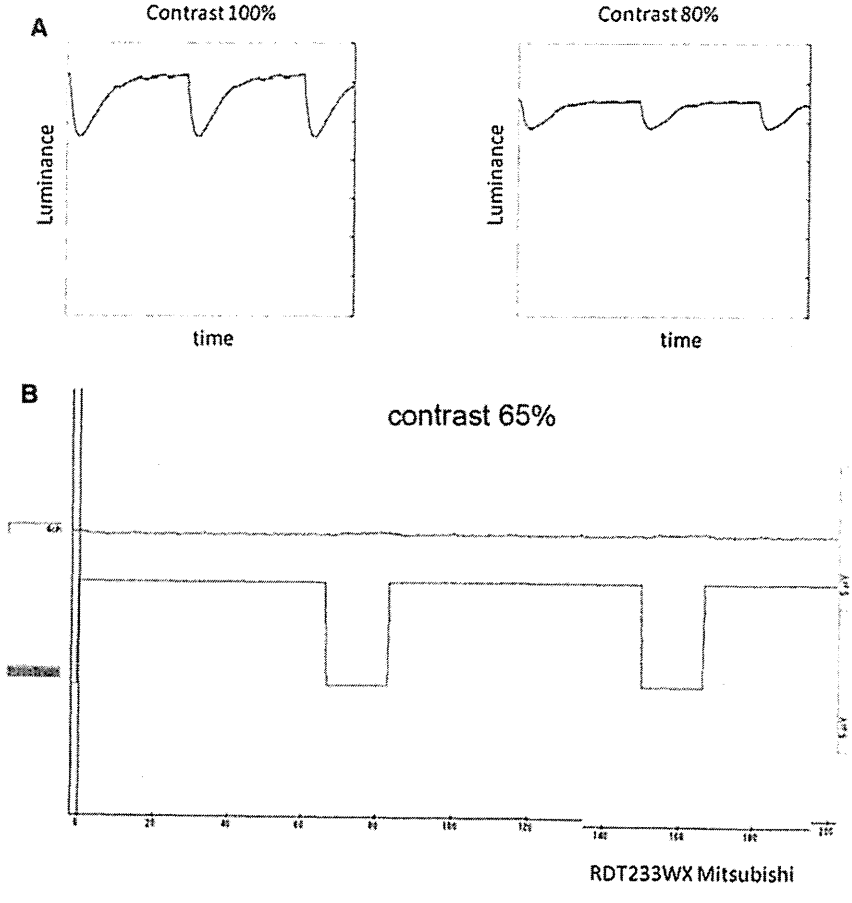

Fig. 4 a The transient change in the luminance was decreased in another LCD monitor (17 in., 340 × 270 mm, RDT233WX, Mitsubishi, Tokyo, Japan). b When the contrast was reduced to 65 %, the luminance artifact was completely removed

Fig. 5 Bland–Altman *plots* for N75-P100 amplitude (a), N75 latency (b), and P100 latency (c). Bland–Altman analysis to evaluate the agreement between two different measures did not show any systematic or proportional error or any dependency on the magnitude of one of the values. But, the individual deviations are not negligible especially for the amplitude (a) considering that the deviation of 3 μV is approximately 30 % of the mean value (11.3 μV)

Osaka, Japan). We confirmed that the variations in the luminance across the screen were within 20 % which complied with the recommendation of the ISCEV standards [1].

The luminance and contrast of the CRT were matched to that of the LCD screen. The contrasts were calculated with the Michelson contrast formula [8].

Pattern-reversal stimuli

The visual stimulus was a black-and-white checkerboard pattern generated on either a CRT monitor (17 in., 320 × 230 mm, S710, Compaq Computer Co., USA) or a commercial LCD screen (17 in., 340 × 270 mm, E170Sc, DELL, TX, USA).

We here define the response time of an LCD panel as the time it takes one pixel to turn from white-to-black or black-to-white. Other investigators have defined the response time as the time required to change from gray-to-gray [2, 3]. The mean luminance was kept at 81 cd/m^2 with a 97 % maximum contrast, and the reversal rate was 3.0 rev/s. The check size was 0.25° at an observation distance of 70 cm. The overall size of the CRT was 19°× 28°, and that for the LCD was 21° × 26.2°. The resolution of each monitor was 800 × 600 pixels, and the vertical frequency was 59.8 Hz.

We found a time delay in the luminance change of the LCD, and this produced a transient change in the average luminance which we named the "flash effect." We predicted that the flash effect would elicit electroretinograms (ERGs) and VEPs. To determine what influence of the flash effect had on the p-VEPs, the screens of both types of stimuli were covered with a diffuser (Kuraray, DFA2-P, Tokyo, Japan).

To minimize the flash effect, the contrast of the checkerboard pattern of the LCD monitor was reduced from 97 to 81 %, and the resulting p-VEPs elicited by each were compared.

Data analysis

The P100 amplitude was measured from the trough of N-75 to the peak of P-100, and the latency of N-75 and P-100 was measured from the onset of reversal to the peak of each component. Student's *t* tests were used to determine the significance of difference.

Table 1 Bland–Altman analysis of amplitude and latency of measurement 1 and measurement 2

	N75-P100 amplitude (μV)	Latency (ms)	
		N75	P100
Measurement 1	11.1 ± 3.1	95.4 ± 4.0	119.1 ± 4.8
Measurement 2	11.4 ± 3.7	95.9 ± 4.2	118.9 ± 4.7
Difference of measurement 1 and measurement 2 (m1 − m2)	0.3 ± 1.6	−0.5 ± 2.1	0.2 ± 2.2
Average of measurement 1 and measurement 2	11.3 ± 3.5	95.7 ± 4.0	119.0 ± 4.7
Percentage of eyes within 1.96 × SD-range (%)	96.2	96.2	96.2

The Bland–Altman analysis did not reveal any systematic or proportional error nor any dependence on the magnitude of one of the values

Results

Changes in luminance of checks of each type of screen

The luminance of the checks is plotted against time in Fig. 2. The luminance of the white checks was caused by a burst of flashes resulting from the luminance spot from the electron beam sweeps ("flies") across the photodiode at 60 Hz on the CRT screen, and a homogenous square luminance pattern on the LCD screen. There was no delay during the change from both black-to-white and white-to-black for the pattern on the CRT screen. In contrast, the luminance was slow to develop and decays on the LCD screen especially from black-to-white. The slow development was due to the time course for the crystal liquid molecules to be aligned to permit light to pass through the polarizing layers. The exact shape of the ascending limb may be different for different LCD screens from different manufacturers.

The input lag was defined as the time between the trigger pulse and the beginning of the luminance change [6, 9], and it was approximately 1.2 ms for the LCD used in this study. The reason for this lag is that the input signal is usually further processed at the display level before the luminance change appears on the screen. These image processing technologies and processing times can vary with the manufacturer, display type, and setup parameters, for example, resolution, color settings, and internal processing [10].

Luminance changes of checks on LCD screens with contrasts of 97 and 81 %

The changes in the luminance of the checks on the LCD screen with stimuli of contrasts 97 and 81 % are shown in Fig. 3. The transient change in luminance is significantly smaller with 81 % contrast. The transient change in luminance on the LCD with stimulus of 60 % contrast was even lower (data not shown). The changes in the luminance on another LCD screen (17 in., 340 × 270 mm, RDT233WX, Mitsubishi, Japan) are shown in Fig. 4.

Recorded VEPs

Comparison of p-VEP components elicited by stimuli generated on CRT and LCD screens

VEPs were elicited by each type of screen, and the amplitudes and latency of the different components were reproducible. Bland–Altman analysis to evaluate the agreement between two different measures did not show any systematic or proportional error or any dependency on the magnitude of one of the values (Fig. 5; Table 1).

The N75-P100 amplitudes are shown in Fig. 6a, and the N75 latency and P100 latency are shown in Fig. 6b, c, respectively. The P100 amplitudes elicited by the LCD screen were not significantly different from those elicited by the CRT screen. However, the latency of N75 and P100 elicited by the LCD screen was significantly longer than those elicited by the CRT screen (Fig. 6b, c).

Comparisons of p-VEPs elicited with or without diffuser placed before CRT and LCD screens

The VEPs elicited by the CRT and LCD screens with and without a diffuser are shown in Fig. 6a. The VEPs elicited with the diffuser place in front of the CRT

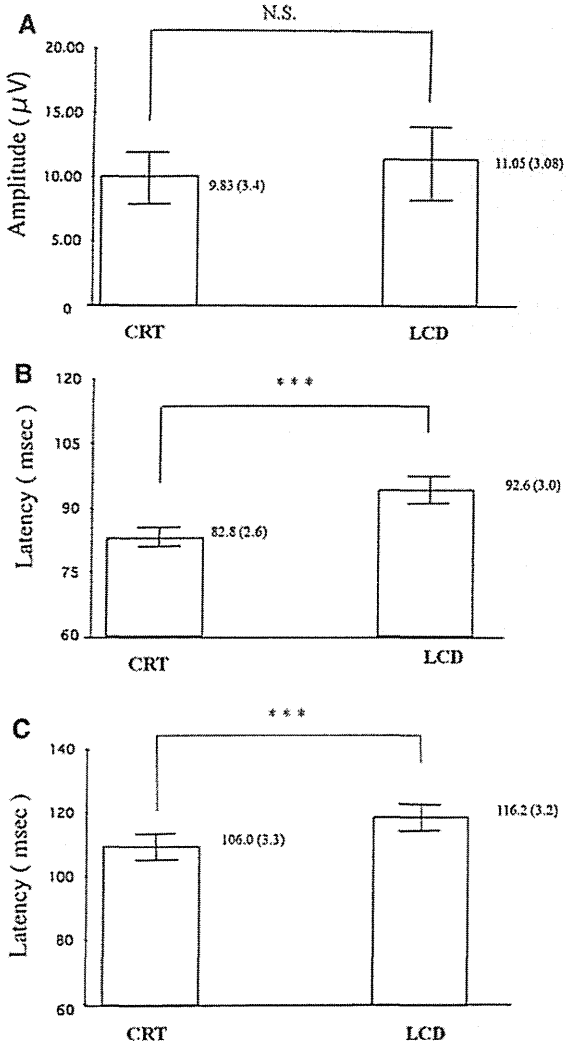

Fig. 6 Comparisons of each parameter between the p-VEP elicited by CRT and by LCD. **a** No significant difference was found in the VEP P100 amplitude elicited by the LCD screen to that elicited by the CRT screen. *NS* not significant. **b** The VEP N75 latency elicited by the CRT and LCD screens. The latency of the VEP N75 elicited by the CRT screen was significantly shorter than that elicited by the LCD screen. **c** The VEP P100 latency elicited by CRT and LCD monitor. There was a statistically significant difference in latency of VEP P100 between those obtained by using CRT and LCD monitor. $***P < 0.05$

monitor were below the noise level, whereas those elicited with the diffuser before the LCD screen had a positive peak at about 100–120 ms. This response was most likely a flash VEP. In addition, when a contact lens electrode was placed on the cornea and the stimulus pattern on the LCD screen was behind a diffuser, a small but distinct ERG was recorded (Fig. 7b).

When the VEPs were elicited with a diffuser before the CRT screen was subtracted from the VEP recorded without the diffuser, the waveform, the N75 and P100 latency, and the N75-P100 amplitude were not changed. When the VEPs elicited with the diffuser before the LCD screen and with 97 % contrast was subtracted from the VEP recorded without the diffuser, the N75 and P100 latencies were not changed but the N75-P100 amplitude was slightly decreased.

Comparison of p-VEP elicited at contrasts of 97 and 81 %

When the VEPs were elicited with the diffuser before the LCD screen with 81 % contrast checks was subtracted from the VEP recorded without the diffuser, no significant change was observed in the N75 and P100 latency and in the N75-P100 amplitude. A comparison of the N75 and P100 latency and the N75-P100 amplitudes of the VEPs elicited by the LCD screen with each contrast are shown in Fig. 8. No significant difference was found in the P100 amplitude between the responses elicited by 81 % contrast stimulus compared to that by using 97 % stimulus (Fig. 8a). No significant difference was observed in the N75 and P100 latency (Fig. 8b, c).

Discussion

The ISCEV standard protocol for clinical visual evoked potentials (2009 update) [1] stated that p-VEPs should be elicited by black-and-white checks that change phase abruptly and repeatedly at a specified number of reversals/s. Further, it stated that there must be no overall change in the mean luminance of the screen, which requires equal numbers of light and dark elements in the display, and no transient luminance changes during the pattern reversal. Thus far, stimuli generated on a CRT screen meet these requirements. But, the LCD screen has an inherent time delay when the luminance changes from black-to-white and also from white-to-black. This delay is the time required for the liquid crystals to align and can cause image blurring during fast-moving scenes [2, 3].

Our results showed that the VEPs elicited by the LCD screen had good reproducibility, but it should be noted that the individual deviations are not negligible especially for the amplitude (Fig. 5a) considering that

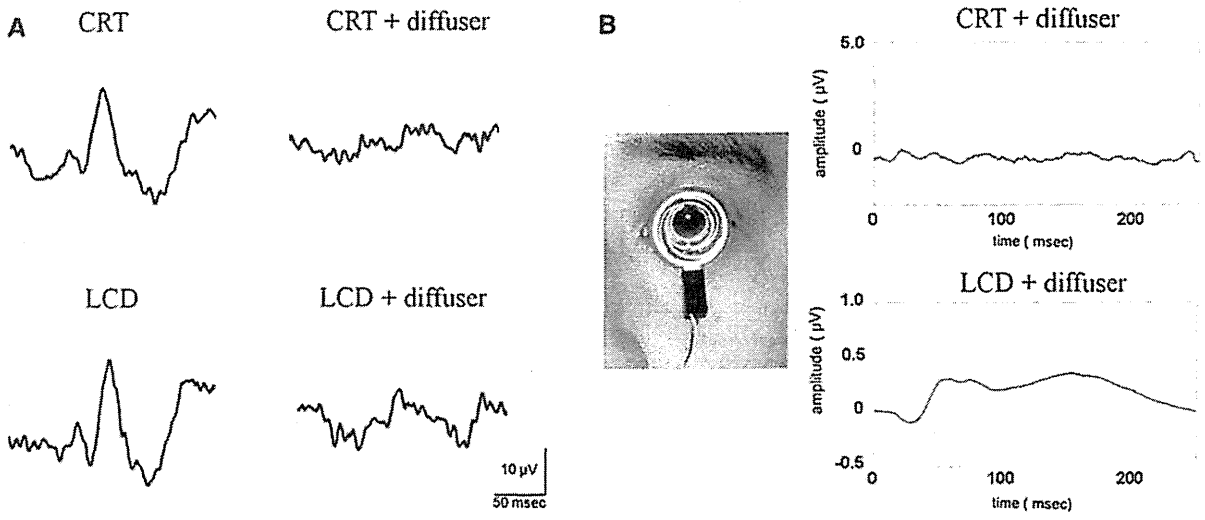

Fig. 7 Pattern visual evoked potentials and electroretinogram elicited by placing a diffuser before each monitor. a VEPs elicited by diffuser on the cathode-ray tube (*CRT*) monitor (*upper*) was below the noise level, whereas those on the liquid crystal display (*LCD*) had a physiological response producing positive peak at around 110 ms (*lower*). b A gold foil contact lens active electrode was placed on the cornea (*left*), and no ERG response was recorded (*upper right*) when the CRT with diffuser was used for stimulation. In contrast, a small but discernible electroretinogram was recorded (lower right) when the LCD with diffuser was used for stimulation

the deviation of 3 μV is approximately 30 % of the mean value (11.3 μV). And when compared to the conventional VEPs elicited by stimuli on a CRT screen, the latency of N75 and P100 was delayed and the N75-P100 amplitude was decreased. These findings are in good agreement with earlier reports [5, 6]. Nagy et al. [6] reported that p-VEP elicited using LCD had longer latency [6]. They attributed the delay to the total temporal differences between the LCD's electronic input and radiometric output signals caused by the response time and the input lag. They showed a model of the relative characteristics of the video and photodiode signals on the oscilloscope. Although it is not known whether this was the case from their figure, the raw value of the luminance change of our monitor was asymmetrical.

Thus, there was a transient change of the mean luminance. Direct monitoring of the luminance changes of our LCD screen showed an input lag of 1.2 ms and a transient change in luminance. The response time according to the specification was 5 ms; therefore, the mean N750 ms of latency delay compared to that when CRT monitor used as stimulator was longer than the sum of the input lag and response time. Because the input lag can be measured easily and is constant, it can be subtracted from delayed latency. But, the influence of the response time on the latency was not fully determined. The input lag and the response time are specific to the LCD monitor, and the information provided by the manufacture as well as measurements by the user is important. In addition, to compare the p-VEPs elicited by stimuli created on the LCD screen to that elicited by the CRT screen, reference to normative data from control group would be recommended.

To determine whether the transient change in the luminance might elicit a flash-evoked physiological response, we recorded VEPs and ERGs with the LCD screen covered by a diffuser. The results indicated that the p-VEPs elicited by the LCD screen were contaminated by f-VEPs. The influence of the flash effect was a prolongation of the latency, but the amplitude was not affected.

The best way to test the luminance changes of LCD screens would be to evaluate the luminance changes by using a photosensor. However, it is time-consuming and expensive, so impractical. Instead, the easiest and least expensive way to check luminance changes during a reversal is to place a diffuser in front of the monitor (Fig. 7) and to let the monitor display a reversal checkerboard pattern of small angle of <0.25°. Our standard way of tuning the luminance of the LCD is first to check the monitor in the default mode. Second, we check the flashing effect with

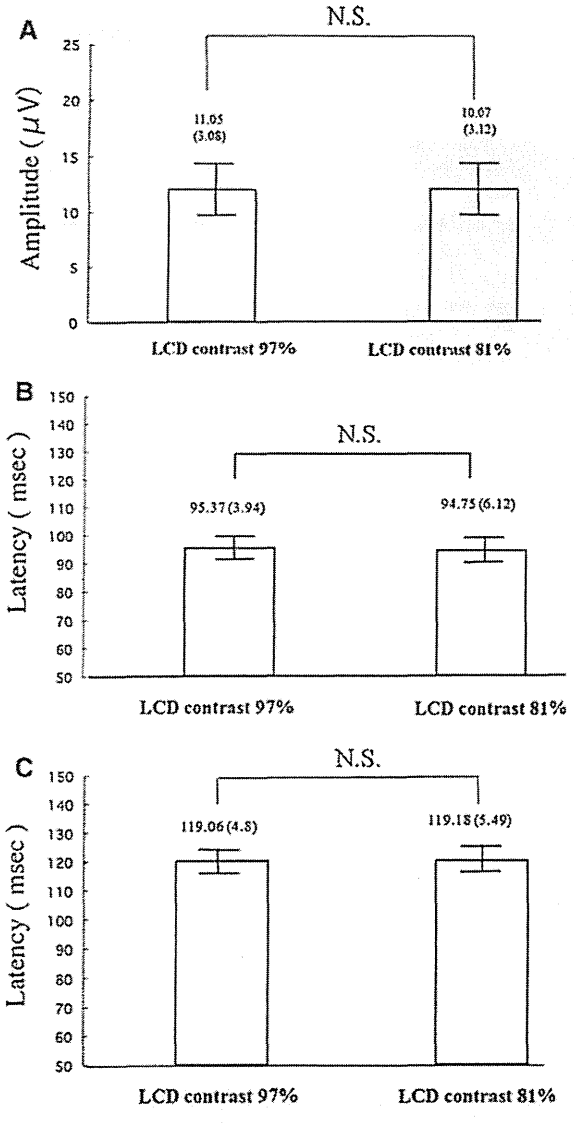

Fig. 8 Comparisons of each parameter between the p-VEP recorded using different checkerboard contrasts of the LCD. **a** No significant difference was found in the P100 amplitude between the responses elicited by 81 % contrast stimulus compared to that by 97 % stimulus. *NS* not significant. **b** and **c** No significant difference was observed in the N75 and P100 latency between the VEPs elicited by 81 and 97 % contrast stimuli. *NS* not significant

diffuser in an above-mentioned way, and third, we check the flashing effect after reducing the contrast of the checkerboard.

However, when using another LCD monitor (17 in., 340 × 270 mm, RDT233WX, Mitsubishi, Tokyo, Japan), the contrast must be reduced to 65 % to completely remove the luminance artifact and such contrast does not match the ISCEV standard.

An alternative way might be to decrease the checksize. For example, if the checksize can be reduced so that one pixel equals one check, then one cannot resolve the pattern when one is sufficiently far away from the screen. In that case, no VEP should be obtained. But, due to the luminance artifact, there should be a sizable VEP, a flash VEP. Given this, the VEP amplitude can be affected depending on the checksize, but it is minimal for standard check sizes.

One of the ways to minimize the flash effect might be to optimize the contrast of the checkerboard luminance. The transient change of the luminance is constant depending on the contrast of the checkerboard and specific to the LCD monitor. The latency delay in the p-VEP is also constant although it did not correspond with the luminance artifact (Fig. 6b, c). A reduction in the contrast of the checkerboard to 81 % still complies with the ISCEV standards (checkerboard pattern contrast $\geqq$80 %) can be considered. However, a reduction in the contrast may not eliminate the flash effect in all LCD monitors in the market. Further investigations on how to eliminate the flash effect are needed.

We did not record pattern ERGs (PERGs). However, when recording PERGs with LCD screens, the responses might be easily contaminated by flash responses. In other words, PERGs might be better suited as an electrophysiological indicator of flash effects. And for those who want to record PERGs with LCD screens, a corresponding validation with PERGs is necessary.

In conclusion, the p-VEP waveforms are affected by a delay in the reversal phase of a checkerboard pattern generated on a LCD screen. The flash effect might be reduced by optimizing the contrast of the checkerboard luminance. The p-VEP recorded using LCD for pattern stimulation is comparable to the conventional p-VEP elicited by checkerboards generated on a CRT screen, when the LCD specific parameters such as input lag and response time are measured and latency delay is corrected.

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Conflict of interest H. Funada is an employee of Tomey Corp., Japan. None of other authors has any commercial relationship.

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