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Impact of Surrounding Illumination on Visual Fatigue and Eyestrain While Viewing Television

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Abstract: The present study investigated the effects of surrounding illumination on visual comfort and fatigue while viewing television. Nine subjects aged 32 to 52 years (mean: 40, standard deviation: 6.8) watched a single 60-min block of film footage with the surrounding illumination and a 60-min block without it. Event related potentials, reaction times to stimuli presented on the television screen, eye blink frequency and subjective ratings of general and visual comfort were used as indices of fatigue and eyestrain. Consistent with earlier published literature on luminance ratios and visual comfort, the surrounding illumination appeared to provide a small improvement in several of these measures.

Key words: Lighting, visual comfort, fatigue, event-related potentials

INTRODUCTION

The focus of the present study was to investigate the impact of surrounding illumination on visual fatigue, eye strain and comfort while viewing television in a dark room. Lighting conditions can contribute to eyestrain and discomfort, such as high luminance ratios (Wibom and Carlsson, 1987) and rapid light level modulation (Jaschinski *et al.*, 1996) even if this modulation is invisible (Wilkins *et al.*, 1989). Since the surrounding illumination feature of the television under evaluation reduced luminance ratios and mitigated the modulation of images displayed on the screen, it was hypothesized that it would reduce these negative effects, especially during prolonged viewing.

Measures of eyestrain and visual fatigue that have been used in prior published study include subjective ratings, blink frequency, reaction time latency and electrophysiological measurement of event related potential (ERP) latency and amplitude.

Regarding subjective ratings, a commonly used instrument for measuring comfort and fatigue in a flight simulator environment is the Simulator Sickness Questionnaire (SSQ) (Kennedy *et al.*, 1993). This questionnaire contains a number of questions pertaining to general comfort, visual comfort and other responses that are commonly experienced by persons using flight simulators for training. Several of these questions are related to relatively severe responses such as dizziness, nausea and sweating, which are not likely to be experienced by casual television watchers. Nonetheless, subjective ratings are useful measures of comfort and fatigue and for these reasons, it was decided to use a subset of questions from the SSQ pertaining to general and visual discomfort as part of the proposed experiment (general discomfort, fatigue and headache for the general comfort questions and eyestrain, difficulty focusing and general visual discomfort, for the visual questions). Subjects responded to these six questions by using a four-point scale (1: none, 2: slight, 3: moderate, 4: severe).

Regarding blink frequency, Stern *et al.* (1994) pointed out that this response often appeared to be a measure of visual fatigue, with increasing frequency of blinking occurring as individuals become more fatigued.

In terms of reaction times, Khek and Krivohlavy (1967) measured individuals' reaction times to visual stimuli over a relatively long (30 min) period of time. They noted that the reaction times over this period tended to become slightly longer and more variable, within this amount of time.

In terms of electrophysiological measurements, by placing electrodes on the scalp of a subject, it is possible to directly measure physiological processes that underlie human information processing, i.e., electroencephalography. Electroencephalography is useful to identify what specific responses occur via information processing in response to stimuli presented to the subject. However, since such responses are usually small in amplitude, they are often hidden behind

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the background brain potentials. Through the ERP methodology, it is possible to extract such hidden potentials by averaging out the background potentials for several stimuli.

Since ERPs directly reflect neural activities, they are widely used to evaluate responses such as mental task load (Yagi *et al*., 1998) and levels of attention and alertness (Picton and Hillyard, 1988). By extension, the ERP is often used to assess the level of fatigue and the contribution of the working environment, including lighting, to fatigue. For instance, Lee *et al*. (2003) measured the deterioration in a specific ERP response parameter called P300, which appears about 300 ms after the onset of a stimulus, over time as subjects participated in a sleep deprivation experiment. The latency of this brain potential response increased and its amplitude decreased as participants became more fatigued. Because there are a number of links between the P300 response and fatigue/eyestrain in the ergonomics literature (e.g., Polich and Kok, 1995), it was decided to incorporate this measure into the experiment.

MATERIALS AND METHODS

In order to identify the type of video content that should be displayed during the experiment, a pilot study was conducted using four subjects (two men and two women), who watched 30 min of a nominally active and of a nominally inactive movie (Bourne Supremacy and Out of Africa, respectively, in counterbalanced order) in a dark room on a flat-screen television (Ambilight, Philips) with no surrounding illumination. Using the modified SSQ (Kennedy *et al*., 1993) subjects were queried on general visual discomfort, general discomfort, fatigue, headache, eyestrain, difficulty focusing. Despite some individual differences among subjects, all of the mean ratings were somewhat higher (indicating greater discomfort, fatigue, eyestrain) after viewing the active content than after viewing the inactive content, although owing to the small population and modest effect size, only the responses to the general discomfort question approached statistical significance ($0.05 < p < 0.1$). Nonetheless, this pre-pilot investigation favored use of the "active" content (in order to maximize negative effects after viewing).

The experiment investigated the effects of surrounding illumination on visual fatigue and comfort. Thus, two lighting conditions, with and without surrounding illumination, were compared by using ERP, blink rates, reaction times and self-fatigue-evaluations as dependent variables.

A mock-up home theater environment was constructed within a laboratory space at the Lighting Research Center in order to provide a natural setting in which subjects could view the television. A photograph of the test space with the television switched on is shown in Fig. 1. During the experiment the illuminance on the face of the television was less than 3 lx.

Nine subjects aged 32 to 52 years (mean: 40, standard deviation: 6.8) participated in two 60 min sessions during the main experiment. This duration was selected to increase the likelihood that some visual fatigue would be present (Khek and Krivohlavy, 1967; Bullough and Rea, 2001). Subjects were paid volunteers from the Rensselaer Polytechnic Institute community but were not affiliated with the Lighting Research Center.

During each session, the surrounding illumination was either turned on (steady white illumination) or off, with the order of the surrounding-illumination conditions counterbalanced across subjects. In each session, a subject viewed a single 60 min long edited version of footage from the action film identified in the pilot study and performed a 6 min fatigue test, during which each subject responded to a self-fatigue-evaluation and performed a detection test.

The self-fatigue-evaluation used five questions developed based on the SSQ (Kennedy *et al*., 1993) with the addition of one modified question. For each question, subjects evaluated their own degree of fatigue using the four point scale summarized above. This was followed by a detection test, in which a series of Landolt C rings were presented in the center of the television screen, one at a time, for approximately 0.5 sec followed by an approximately 1.5 sec interval. Each ring had four potential gap orientations; up, down, left, or right. The subjects' task was to respond to every presentation of a ring that displayed a right-oriented gap. This task showed 144 rings in total (presented in random order); 36 of the 144 rings (25%) had right-oriented gaps.

During these detection tests, electroencephalograms (EEGs) and electrooculograms (EOGs) were recorded by a computerized data logger and data analysis system at 1024 Hz (Active Two, Biosemi). EEGs were measured by three electrodes placed at the Cz, Pz and Oz electrode sites of the international 10-20 system (Anonymous, 1991) to analyze brain potentials. From the recorded brain potentials, event related potentials (ERPs) were calculated. EOGs were measured by two electrodes placed above and below either the left or right eye. Since when an eye blink occurs, a sharp spike appears in EOGs, eye blinks can be easily identified. The computer system also recorded onsets of target presentations and subjects' responses to the target presentations for subjects' reaction time measurements. Eye blink rates were measured while subjects watched the film footage, during

Fig. 1: View looking into the experimental test space. Surrounding illumination was presented along the left and right side of the television display

the first 5 min, the middle five min and the last five min of each 60 min block of footage.

Prior to the initial detection test, all subjects were given a three-minute practice session since it was noted that subjects required some time to become familiar with the detection task.

RESULTS

Subjective ratings: The subjective ratings are summarized in two ways: in terms of the mean ratings from the questionnaire given after watching each 60 min segment (as described earlier, higher rating scores correspond to greater discomfort) and in terms of the mean changes in ratings between the questionnaire given before and after each 60 min segment (the 'after response' minus 'before response'). Comparisons between the conditions with the surrounding illumination on and off use the two-tailed Student's t-test and are summarized in Table 1 and 2.

Overall, all of the subjective ratings were consistent with greater fatigue, eyestrain and discomfort with the surrounding illumination off. Only for two of the ratings (difficulty focusing and sleepiness) the differences between the mean ratings were statistically significant.

Results for the changes in subjective ratings after watching each 60 min segment are presented in Table 2. These data were derived by taking the difference in rating for each subject and averaging the differences across subjects. This measure is intended to determine whether there were differences in the changes in the ratings after 60 min of television watching, between the surrounding illumination conditions. Unlike the results based on the mean ratings above, which showed a consistent trend of the surrounding illumination resulting in a lower rating (less uncomfortable) for all subjective measures, the results in Table 2 are less clear in terms of favoring either condition.

Table 1: Summary of mean subjective ratings with surrounding illumination on and off

Average rating after watching 60 min	On	Off	p (two-tailed) t-test
General visual discomfort	1.50	1.56	$p>0.05$
General discomfort	1.44	1.67	$p>0.05$
Fatigue	1.78	2.22	$p>0.05$
Headache	1.33	1.44	$p>0.05$
Eye strain	1.44	1.56	$p>0.05$
Difficulty focusing	1.44	1.89	$p<0.05$
Sleepiness	1.89	2.56	$p<0.05$

Table 2: Summary of mean changes in subjective ratings with surrounding illumination on and off

Average change after watching 60 min	On	Off	p (two-tailed) t-test
General visual discomfort	0.28	0.22	$p>0.05$
General discomfort	0.22	0.22	$p>0.05$
Fatigue	0.22	0.33	$p>0.05$
Headache	0.22	0.22	$p>0.05$
Eye strain	0.33	0.22	$p>0.05$
Difficulty focusing	0.33	0.78	$p>0.05$
Sleepiness	0.33	0.83	$p>0.05$

Eye blinks: Figure 2 shows the average rate of eye blinks per second (EPS) over the course of the entire experiment. As discussed earlier (Stern *et al*., 1994), an increase in EPS indicates an increase in visual fatigue. Times 1-3 (first, middle and last five min) represent EPS for the first 60 min session and times 4-6 (first, middle and last 5 min) represent EPS for the second 60 min session. Due to the counterbalanced experimental design, each time represents a combination of both surrounding illumination conditions. An overall trend of increasing EPS with time is clear. However, when considering each session separately (for both surrounding illumination conditions), the 'end' data (collected during the last five min of viewing) shows a decrease in EPS relative to the 'middle' data (collected during the middle five min of viewing). One potential reason for these findings maybe due to differences in film content (e.g., increased screen action during the last five min of data relative to the other data collection times, could have increased subjects' interest in viewing and suppressed the influence of fatigue on eye blink rate).

Figure 3 shows mean EPS, comparing the two lighting conditions. While the surrounding illumination resulted in slightly lower EPS, the difference between the two conditions was not significant (two-tailed t-test, $p > 0.05$).

The average change in EPS, for both surrounding illumination conditions, when comparing the first ('start') data collection period to either the second ('middle') or last ('end') data collection period, was also calculated. When comparing the change in EPS from 'start' to 'middle,' the surrounding illumination condition resulted in a higher rate of increase in EPS, although there were large variances associated with each condition. There was not a significant difference (two-tailed t-test, $p > 0.05$) between the two conditions. The reverse trend was seen when comparing the change in EPS from 'start' to 'end,' though again the variance was large and no statistically significant difference between conditions (two-tailed t-test, $p > 0.05$) was demonstrated.

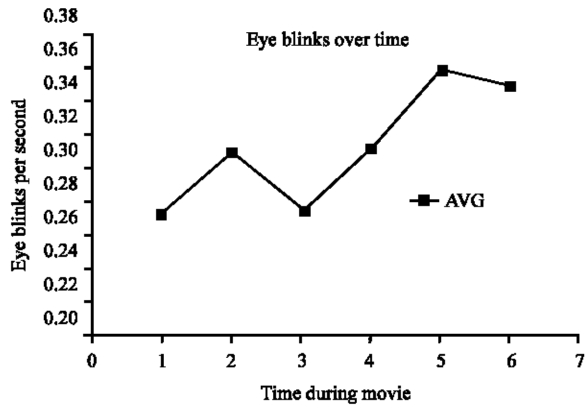

Fig. 2: Mean eye blink rate throughout the experimental sessions. Times 1-3 represent the average eye blink rate for the first session of the experiment and times 4-6, the last session of the experiment. Note that each time represents a combination of surrounding illumination conditions

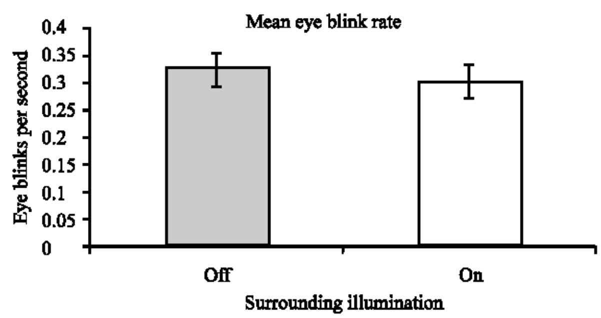

Fig. 3: Mean eye blink rates for the two surrounding illumination conditions (±standard error of the mean)

Reaction time latency: In a similar manner to the subjective rating and eye blink data, the reaction time data were analyzed by comparing the absolute values of the reaction times between the surrounding illumination conditions for the end of each session and by comparing the change in reaction time (between the start and end of each session) for both lighting conditions.

Although there were slightly longer absolute reaction times under the surrounding illumination, these differences were not statistically significant using a repeated-measured analysis of variance ($p > 0.05$).

When evaluating the change in reaction times between the start and end of each 60 min session for both surrounding illumination conditions, reaction times actually were slightly improved (shorter) after 60 min of viewing in both conditions. The magnitude of these improvements were slightly larger without surrounding illumination, in an opposite direction as hypothesized, although the difference in reaction time changes between the two conditions was not statistically significant using a paired, two-tailed t-test ($p > 0.05$).

ERP response: The amplitude and latency of the P300 electrophysiological response in subjects' ERPs were measured as indices of the degree of visual fatigue influenced by lighting conditions. This is because recent studies (Lee *et al*., 2003; Kaseda *et al*., 1998) showed that as subjects become fatigued the latency of the P300 component is increased and that its amplitude is often decreased.

As described above, the Landolt C ring target with the gap oriented toward the right side was presented 36 times during each detection test. ERPs corresponding to those 36 target presentations were extracted through the following procedure:

- 36 sets of brain potentials time-locked to the onsets of the 36 target presentations were collected, covering from 1000 ms in latency before each target onset to 2000 ms after the onset. Each set of the brain potentials consisted of three brain potential functions corresponding to the three electrode locations, Cz, Pz and Oz.
- Each of the 36 sets of brain potentials was visually inspected and the ones which were contaminated with artifacts (e.g., eye blinks and muscle potentials) were eliminated.
- The 36 (or fewer) sets of brain potentials were averaged and three sets of ERPs for the Cz, Pz and Oz electrode locations were extracted.

A computer program for EEG analyses (EEGLAB, University of California-San Diego) was used for the earlier described analyses. This program is an interactive toolbox for processing continuous and event-related EEG and other electrophysiological data from existing software (Matlab, Mathworks) using independent component analysis (ICA), time/frequency analysis and other methods including artifact rejection (Delorme and Makeig, 2004).

After the earlier extraction procedure, the number of brain potential sets that could be used in further analyses ranged from 10 to 36 (averaging 28). Although subjects were instructed to try to avoid blinking for 2 sec after each target presentation, many brain potential sets needed to be eliminated because of contaminations of eye blinks.

Figure 4 shows three sets of ERPs measured at the Cz, Pz and Oz areas, averaged for all nine subjects and for all four detection tests. As seen in this figure, there are large peaks at a latency of approximately 375 ms for all three electrode measurements. Those peaks represent P300 components, although their latencies are not exactly 300 ms-it is known that the peak latency of P300 is often shifted between 250 ms to 600 ms (Hugdahl, 1998).

This study individually identified peak latencies and amplitude of P300 components based on ERPs obtained from all four detection tests in each television lighting condition. Data were analyzed from both ERPs from the Cz and the Pz areas.

The mean P300 latencies and amplitudes were derived from the detection tests after watching television since those data are considered to be influenced by the viewing experience immediately before the target presentation. As described earlier, it is assumed that a subject can be considered as being more fatigued as the P300 latency increases. In addition, a subject is supposed to be more fatigued as the P300 amplitude reduced. In most cases, except for the P300 amplitude from the Cz area, subjects appeared to be less fatigued with the surrounding illumination switched on than with it switched off. To statistically explore such tendencies, statistical analyses (two-tailed t-tests) were applied to all subjects' data. The results suggested, however, that there were no significant differences between the lighting conditions for either of these indices in either of the brain regions studied.

Comparing between the surrounding illumination conditions based on absolute values of P300 latencies and amplitudes might not be appropriate for fatigue analyses because the degree of a subject's fatigue often varies due to other factors such as time of the day and the order of experimental conditions. To minimize the effects of these factors on the initial status of a subject's fatigue, therefore, differences in latency and amplitude of the second detection test (after watching television) from the first detection test (before watching television) were addressed in subsequent analyses.

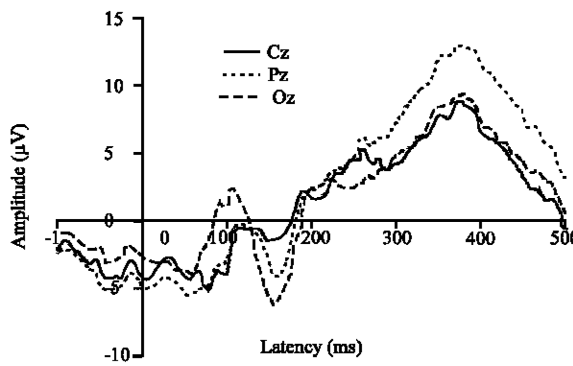

Fig. 4: Averaged ERPs for nine subjects and for all four detection test sessions

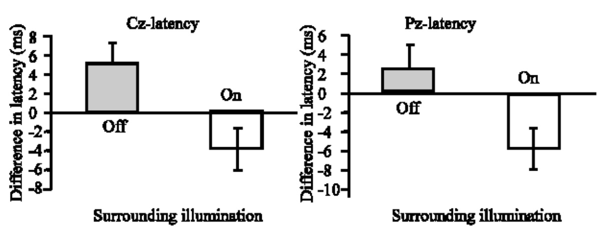

Fig. 5: Difference in P300 latency in ERPs from Cz and Pz between the first and second detection tests (± standard error of the mean)

Figure 5 shows differences in P300 latency of ERPs from Cz and Pz between detection tests before and after watching television. Figure 5 also includes standard errors of means and generally suggests that P300 latencies in the Cz and Pz areas appear to be prolonged due to viewing television without surrounding illumination. In contrast, P300 latencies from Cz and Pz appear to be shortened under the surrounding illumination condition. This is consistent with subjects becoming more fatigued by watching television without the surrounding illumination while the degree of fatigue was improved (eased) by watching television with this illumination. To statistically confirm these tendencies, two-tailed t-tests were applied to all subjects' data. The results of the two-tailed t-tests suggested that there were significant differences in the change in P300 latency in ERPs recorded from Cz between the two lighting conditions ($p < 0.01$), while no significant difference was shown in ERPs recorded from Pz ($p > 0.05$).

Regarding the differences in P300 amplitude of ERPs from Cz and Pz between the detection tests before and after watching television, the amplitudes in both areas were increased after viewing television with and without surrounding illumination. To statistically explore whether there were any differences between the two lighting conditions, two-tailed t-tests were applied to all nine subjects' data. However, the results of the t-tests suggested that there were no significant differences in the change in P300 amplitude In ERPs recorded from Cz and Pz between the two lighting conditions ($p > 0.05$ for both channels).

DISCUSSION

The results of this experiment indicate that subjects were likely less fatigued and experienced less eyestrain with surrounding illumination present than without surrounding illumination, in terms of a number of the measures used (self-fatigue-evaluations, eye blinks, reaction times and the amplitude and latency of P300). The effects were modest in magnitude.

The fact that not all measures identified statistical significance and that in some cases (e.g., the reaction time data) opposite-from-expected results were found, indicates perhaps that the degree of fatigue and eyestrain under conditions corresponding to about an hour of television viewing is just reaching the threshold of being able to be detected using the dependent measures identified here.

Some of the unexpected results, such as the lack of differences in ERP amplitude, could be based on difficulty in interpreting just what these measures indicate. A recent study using calculation tasks led to a consistent tendency that the degree of fatigue was significantly reflected in P300 latency but not in P300 amplitude (Kaseda *et al*., 1998). Although no literature identified for this study has clearly stated whether and why the P300 latency might more consistently reflect the degree of fatigue than the P300 amplitude, this might be because amplitudes of brain potentials are often affected by background noise such as power fluctuations in electricity.

It is worth noting, however, that whenever a statistically significant effect was identified, it was always in the hypothesized direction, whereby the surrounding illumination would appear to reduce eyestrain and visual fatigue, by reducing the ratio of luminances of the screen and the walls around the television set (Wibom and Carlsson, 1987) and by reducing the amplitude of intensity modulation of the field of view (Jaschinski *et al*., 1996).

It should also be recognized that recreational viewing of television is a very common activity in Western nations and not one that is necessarily associated as a visually demanding, difficult task. One might not expect there to be large differences even with the addition of surrounding illumination. The inherent variability among subjects and possible effects such as viewing material, time of day and other factors are a challenge to the design of such studies. Short of running such a study with a clinical-size subject sample (100 or more subjects), which we do not recommend in the present context, it would likely be difficult to obtain results with stronger trends, especially when keeping within the constraints of providing a somewhat realistic viewing experience.

In summary, then, the presence of surrounding illumination does appear to provide a modest benefit with respect to eyestrain, visual comfort and fatigue, over conventional television viewing without this feature. The effects are small, but when they appear in terms of statistically significant effects, they consistently show a benefit. Such converging operations (using different measures to capture the response) are a strong component in reinforcing this conclusion.

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