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Eyelid Squint Response to Asthenopia-Inducing Conditions

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ABSTRACT

Purpose. To study the orbicularis oculi muscle response to asthenopia-inducing conditions.

Methods. Twenty subjects (18–36 years) screened for 20/20 vision in each eye participated in the study. Subjects read passages under different asthenopia-inducing conditions. The inducing conditions were glare, low contrast, small font size, refractive error, up gaze, accommodative stress and convergence stress. Surface electromyography (EMG) was used to study the orbicularis oculi response from the right eye. Palpebral fissure height was measured from recorded video images of the right eye. At the end of each condition subjects were asked to rate the severity and type of visual discomfort experienced.

Results. Outcome measures for the asthenopia-inducing conditions were compared with their respective nonstress controls. Repeated measures analysis of variance was used to analyze the data. Refractive error ($p = 0.0001$), glare ($p = 0.0001$), low contrast ($p = 0.007$), small font ($p = 0.034$), and up gaze ($p = 0.001$) resulted in a significant increase in EMG power. Refractive error ($p = 0.0001$) and glare ($p = 0.0001$) also caused significant reduction in aperture size. Reading a low contrast text caused a reduction in blink rate ($p = 0.035$), whereas refractive error ($p = 0.005$) and glare ($p = 0.01$) caused an increase in blink rate. All conditions induced significant visual discomfort ($p < 0.001$).

Conclusion. Refractive error and glare, which reduce image quality and benefit from eyelid squint, caused increased EMG power, eyelid squint response and increased blink rate. Low contrast and small font, which reduce image quality but do not benefit from eyelid squint, resulted in increased EMG power without changes in aperture size and reduced blink rate (for low contrast). Accommodative and convergence stress (in subjects with normal accommodative and vergence abilities) did not cause changes in EMG power, aperture size or blink rate. These results suggest that contraction of the orbicularis oculi is a part of the asthenopia mechanism related to compromised image quality.
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Key Words: asthenopia, orbicularis oculi, eyestrain, eyelid squint, surface electromyography

Asthenopic symptoms are common among computer users and others who perform demanding visual tasks. Viewing under visually stressful conditions such as glare, compromised image quality, or with elevated gaze angles cause dry-eye-like symptoms.[1, 2] Reading from a computer display or from hard copy can cause a reduced blink rate, which is plausibly related to dry-eye-like symptoms. Vision disorders such as convergence insufficiency, decompensated heterophoria, accommodative dysfunction, and uncorrected refractive error have been reported to result in symptoms of eye ache, double vision, blurred vision and headache.[3–9]

Two constellations of symptoms, labeled "external" and "internal" were identified by Sheedy et al. based on the type of sensation, perceived location and the asthenopia-inducing condition.[10] External symptom sensations were burning, irritation, and dryness (similar to the commonly identified symptoms related to dry eye) and were perceived to be at the front and bottom surfaces of the eye. The conditions that induced external symptoms were manually holding open the eyelids, up gaze, glare, small font, and flicker. The internal symptoms were strain, eye ache, and headache, induced by accommodative, convergence, and refractive error stress, and were perceived to be located inside the eye.

Even though knowledge of asthenopia has existed for decades, little is known about its physiological basis. Fugate and Fry (1956) proposed increased pupillary hippus due to the opposing action of the sphincter and the dilator muscles as a possible mechanism for glare-induced asthenopia.[11] However, Howarth (1993) studied the pupillary behavior under glare and non glare conditions and found no significant difference between the two.[12] The role of the orbicularis oculi in asthenopia was suggested by Berman et al. (1994) who used skin electromyography (EMG) recordings of the orbital portion of the orbicularis oculi muscle and measured increased power output in the presence of a glare stimulus compared with no glare.[13] The orbicularis oculi muscle is functionally subdivided into the orbital and the palpebral portions. Contraction of the palpebral portion results in blink; contraction of the orbital portion is required for forceful eyelid closure.[14] Eyelid squint has been shown to provide two potential benefits to the person: improved visual acuity in the presence of refractive error and decreased retinal illumination under conditions of glare.[15]

Reading or working at the computer has been shown to result in a reduced blink rate. Tsubota and Nakamori (1993) measured reduced mean blink rate while reading and viewing a computer display compared with relaxed conditions.[2] The mechanisms that link reading, reduced blink rate and dry eye symptoms are not clear. It has been suggested that blinks interfere with acquiring visual information during reading and therefore are inhibited.[16] Holland and Tarlow (1972) showed that blink rate was reduced with increased mental load.[17] Sheedy et al. (2005) showed that maintaining different levels of voluntary eyelid squint reduced blink rate.[18] Profound reduction in blink rate along with increased exposure of the ocular surface area due to elevated gaze angles noted in computer users, have been proposed as contributing to dry eye symptoms of computer users.[2]

We hypothesize an interaction between eyelid squint, blink rate and the dry-eye-like symptoms experienced by computer users. If eyelid squint is part of the asthenopia pathway, then the fact that small levels of eyelid squint can be detected with the surface EMG offers potential as an objective measurement. The purpose of the current study is to determine the orbicularis oculi activity, eyelid squint response, and blink rate while reading under asthenopia-inducing conditions.

METHODS

Subject Population and Inclusion Criteria

Subjects were screened for unaided 20/20 or better monocular visual acuity. Acuity was also tested with and without a +1.00 DS lens monocularly to screen for uncorrected hyperopia. A reduction in acuity with the +1.00 DS lens indicated absence of significant uncorrected hyperopia. Other criteria for inclusion were a minimum of 10 cycles/min accommodative facility (with ±1.50 DS accommodative flipper), near point of convergence of 6 cm or better, and absence of any ocular diseases, clinically diagnosed dry eye or asthenopic symptoms before beginning the study. Twenty subjects (13 female and 7 male) aged 18 to 36 years were enrolled into the study from the student population of the Ohio State University. Voluntary consent was obtained according to protocol approved by the Ohio State University Institutional Review Board. This research adhered to the tenets of the Declaration of Helsinki.

Procedure

Subjects were comfortably seated with their head supported by a forehead and chin rest with the reading material (selected from the works of Sir Arthur Conan Doyle) placed 60 cm from their eyes. Surface electromyography (Model 15LT Physiodata Amplifier system (Astro-Med Inc., Grass Product Group, RI) with four 15A54 amplifier banks) was used to obtain potentials from the orbicularis oculi muscle. Skin was prepared with a mild abrasive. Conducting and adhesive gel were used to keep the electrodes in place. A pair of 4-mm active recording electrodes, with a 1-cm separation, was attached 1.25 cm below the lower lid margin midway between the medial and lateral canthi of the right eye; this electrode location picks up potentials from the muscle during eyelid squint and blink. A reference electrode was attached to the right ear lobe. Grasslab v1.1 software was used to obtain and analyze the data. The data were sampled at 1000 Hz with a high pass filter at 30 Hz and a notch filter at 60 Hz. Amplification was set to 5×1000. The amplifier was internally calibrated to a DC voltage of 50 μV.

A video camera (with infra red illumination and a 1.75× magnification) was used to image the eye and the video was saved using a WinTV recorder. A centimeter ruler imaged in the plane of the eye was used to calibrate the images. The eye images were analyzed post hoc to obtain palpebral fissure heights. The maximum vertical distance between the upper and lower lid was measured using an onscreen ruler. The resolution of the onscreen ruler was 1/38 of a centimeter. Thus it is unlikely that any change in palpebral fissure height was undetected because of a limitation of the measuring equipment. Closing and opening the eye before every trial served as a critical event to synchronize the video file and the EMG recording.

Measures of EMG total power, palpebral fissure height and blink rate were first obtained for 5 min as the subject silently viewed a printed picture of a natural scene, which was matched in field size to the reading material. After the picture viewing task, subject read under a non-stress-inducing condition for 15 min. This condition is referred to as the "default nonstress condition." A picture was used to obtain the EMG measure (under relaxed conditions) before the default nonstress reading, in order to study (if any) the effects of eye movements during reading on the EMG measure.

The middle of each page of the reading material was aligned about 10° below the straight ahead gaze. The asthenopia-inducing conditions were presented in a random order determined by Latin square, after the default nonstress condition. One page of "nonstress" reading preceded each of the asthenopia-inducing conditions and served as "respective nonstress control." The conditions tested are described in Table 1. The asthenopia-inducing conditions were subjectively predetermined to be approximately equal at inducing ocular discomfort.

The asthenopia-inducing trials ended when the subject claimed that the symptoms became barely tolerable (i.e., the subject could no longer read because of the induced symptoms) or 15 min—which ever occurred first. A 5-min rest period was given between reading trials. In an earlier study by Sheedy et al. (2003) (that used similar asthenopia-inducing conditions) 5 min of relaxation between the conditions was determined to be sufficient based on the symptom scores. Outcome measures for the asthenopia-inducing conditions were compared with their preceding nonstress controls, thus accounting for carry over effects, if any, from the previous conditions. Settings for the nonstress controls, preceding each of the asthenopia-inducing conditions, were identical. Therefore any difference in EMG measures between the nonstress controls would represent change in muscle response to the same condition with

TABLE 1.
Asthenopia-inducing conditions in this study

Conditions	Description
Nonstress condition	Text was printed in 10 point Verdana font, presented at 60 cm. The middle portion of the page was about 10 degrees below the straight ahead gaze.
Refractive error	Subjects viewed with mixed astigmatic refractive error of +2.00/−4.00 ×180 OU created with spectacles. Spectacles were selected from three pairs with different pupillary distances.
Glare	Two tungsten bulbs (60 W) at about 30 degrees superior to the straight ahead position and 5 degrees apart were directly facing the subject's eyes. Luminance of the glare source was measured to be 24,000 cd/m^2 and that of the reading material 1000 cd/m^2.
Small font size	The reading material was printed in 5 pt size, presented at 60 cm. The horizontal and vertical limits of the text on the page were matched to that of the default text.
Low-contrast text	10-pt Verdana text was printed on white paper using gray color for the font that made the text barely readable. The contrast was calculated to be 3.5% from luminance measures obtained for the text and the background with a Pritchard photometer. The contrast was calculated using the formula $(L_{max} - L_{min})/(L_{max} + L_{min})$.
Accommodative stress	Subjects held a lorgnette with +1.50 DS lenses in one hand and a lorgnette with −1.50DS lenses in the other and switched lenses for each line of text. Subjects were instructed to keep the text clear as they switched between the lenses.
Convergence stress	Subjects read text at 16.7 cm through +6.00 DS lenses. Text was 3-pt Verdana, calibrated to subtend the same visual angle and field as a 10 pt font at 60 cm. The text was aligned such that the middle of the page was about 10 degrees from the straight ahead gaze. Spectacles were selected from three pairs with different pupillary distances in order to minimize the prismatic effect of the lenses.
Up gaze	The reading material was mounted such that the middle of the page was 25 degrees above the straight-ahead gaze and at a distance of 60 cm from the plane of the eyes.

time. Questions based on the reading material were administered after every trial to normalize subject attention to the task.

Subjects were asked to draw a vertical line along a 100-mm analogue scale to represent the severity of the symptoms experienced. The symptoms tested were: burning, irritation, dryness, tearing, eye ache, muscle strain, blurred vision, double vision, headache, tired eyes and total visual discomfort. Equally spaced labels on the 100-mm line indicated none, mild, moderate, bad and severe as levels of severity. Zero represented none and 100 represented severe. Subjects also estimated the time they spent reading the text after completion of each condition.

Data Analysis

The outcome measures were EMG power, palpebral fissure height, blink rate, and symptom scores. EMG data and palpebral fissure heights were analyzed from 3 s blink-free periods when the subject was reading the middle of each page and were averaged across pages for every condition. Total EMG power was calculated using the Grasslab Reviewer software's FFT algorithm. Because blink-free traces were selected, the total EMG power obtained was a measure of the tonic level of contraction of the orbicularis oculi muscle. Blinks were manually counted from the video recordings for each of the conditions and their respective nonstress controls. Palpebral fissure height is a measure that accounts for vertical movement of the upper and lower lids either independently or together. The analogue symptom scale was scored from 1 to 100 by measuring the location of the vertical line along the 100-mm scale.

Statistical Analysis

Repeated measures ANOVA was used to compare the log-transformed data for palpebral fissure height and EMG power, between the respective nonstress controls and the asthenopia-inducing conditions. In order to perform a similar comparison for the default nonstress condition, the outcome measures obtained from the first page of reading under this condition was compared with the average from the rest of the pages read under the same condition. For example if the subjects read 10 pages of text for 15 min under the default non-stress-inducing condition then the measure from page one was compared with the average from the rest of the nine pages. Thus the mean ratio of 1.04 reported in Table 3 was obtained by comparing the first page measures with the average from the rest of the pages (within the default nonstress condition) across all the subjects.

Bonferroni correction was made for post hoc multiple comparisons. The p values reported are the adjusted p values and not the actual p value. The adjusted p value is obtained by multiplying the actual p value by the number of comparisons. Log transformation was done in order to account for the skewed nature of the data.

RESULTS

Orbicularis Oculi Response to Asthenopia-Inducing Conditions

The EMG measures of power for the default nonstress condition did not differ from the values obtained for picture viewing. Therefore the eye movements involved in reading do not cause significant increase or decrease in the EMG measures. EMG power was significantly higher than the respective nonstress control conditions for refractive error ($p < 0.0001$), glare ($p < 0.0001$), low contrast ($p = 0.007$), small font ($p = 0.034$), and up gaze ($p = 0.001$). Table 2 summarizes the mean EMG power ratios between the asthenopia-inducing conditions and their respective nonstress

TABLE 2.
Ratio of electromyography power between asthenopia-inducing conditions and their respective non-stress controls

Conditions	Mean ratio	95% CI		p
		Lower	Higher	
Default nonstress	1.02	0.92	1.14	0.137
Refractive error	54.41	17.12	172.94	<0.001
Glare	2.95	2.01	4.34	<0.001
Low contrast	1.68	1.17	2.41	0.007
Small font	1.42	1.03	1.95	0.034
Up gaze	2.03	1.37	3.03	0.001
Accommodative stress	1.51	0.94	2.43	0.088
Convergence stress	1.16	0.81	1.67	0.390

controls. Figure 1 represents EMG traces, from a representative subject, for the different asthenopia-inducing conditions.

The average palpebral fissure height measured during picture viewing was 10.25 ± 1.98 mm and during reading under default nonstress condition was 10.27 ± 1.77 mm. These two measures of aperture size were not significantly different from each other. Significant reduction in palpebral fissure height (eyelid squint) was measured for glare ($p < 0.001$) and refractive error ($p < 0.001$). Up gaze ($p < 0.001$) and the default nonstress condition ($p = 0.016$) showed a statistically significant increase in aperture size. Table 3 summarizes the mean palpebral fissure height ratios for the asthenopia-inducing conditions.

There were no significant differences in EMG measures or palpebral fissure heights obtained from each page of text within the reading trial duration for any of the conditions or the default nonstress control.

Blink Rate and Asthenopia-Inducing Conditions

Blink rate (Fig. 2) was reduced during reading (10 blinks/min for default nonstress condition), when compared with viewing a picture (16 blinks/min, $p = 0.001$). Compared with nonstress reading, low contrast resulted in a statistically significant reduction in blink rate ($p = 0.041$), whereas glare ($p = 0.003$) and refractive error ($p = 0.005$) resulted in an increase in blink rate.

Stress Effects Over Time

There was a significant linear increase ($p = 0.005$) in EMG power ($p = 0.015$) for the nonstress control conditions (that preceded every asthenopia-inducing condition) with time, as shown in Figure 3. This increase in EMG measure could be due to stress build-up, even though subjects were allowed to relax for 5 min between trials. Increasing the relaxation time in between conditions would probably reduce the build up of stress over time. No significant change in palpebral fissure height or blink rate was measured in the nonstress controls with time.

Symptoms and the Inducing Conditions

Symptoms across all conditions were grouped into internal and external based on the two categories from the results obtained in a previous study.[10] Eye ache, muscle strain, headache, double vision and tired eyes were grouped under internal factors; burning, irritation, dryness and tearing were grouped under external factors. Rather than using the scoring coefficients from the previous study, separate single factor principal component analyses were run for the internal and external symptoms based on the previous study definitions. Table 4 shows the correlations between each symptom and the computed internal and external score. For purposes of this table when each symptom was correlated with its respective factor score, the factor score was first recomputed dropping the symptom of interest. For example when correlating the external symptom burning with the external factor, an external factor score was first developed using irritation, dryness, and tearing without burning included. We did not want to bias the correlation by using factors that included the symptoms we were testing. A t-test of the correlation coefficients demonstrated that internal symptoms were more highly correlated with the internal factor than with the external factor ($p < 0.05$) and the external symptoms were more highly correlated with the external factor ($p < 0.05$). Internal and external factor scores were not independent as their correlation was significant at $r = 0.72$.

Even though the grouping of the symptoms were the same as in the previous study,[10] the asthenopia-inducing conditions were not as discriminative of the internal and external symptoms they caused. Significant differences between the two symptom groups emerged only for the default nonstress condition ($p = 0.001$), accommodative stress condition ($p = 0.002$) and the glare condition ($p = 0.001$). The lack of discrimination between the two groups by conditions might have been due to the high correlation between the internal and external symptoms seen in this particular pool of subjects.

Table 5 shows that all of the asthenopia-inducing conditions resulted in greater discomfort than did the default nonstress conditions, indicating that the conditions did result in visual discomfort. Although the discomfort score was similar for most conditions, induced refractive error resulted in a significantly higher score ($p < 0.05$) compared with other conditions.

Table 6 shows the difference between subjective estimates of time spent and actual time spent in reading under the default nonstress and asthenopia-inducing conditions. The differences are significant for conditions of low contrast, small font, up gaze and convergence stress. Results indicate that the subjects on an average felt they spent more time reading the text under asthenopia-inducing conditions compared with the actual time spent.

DISCUSSION

The results are summarized in Table 7. The asthenopia-inducing conditions used in this study may be classified into three different groups based on the magnitude of the EMG response and the measured palpebral fissure heights. The up-gaze condition is not categorized here and is discussed separately.

1. *Group 1:* Refractive Error, Glare.
   Increased orbicularis oculi EMG, reduced palpebral fissure height and increased blink rate.

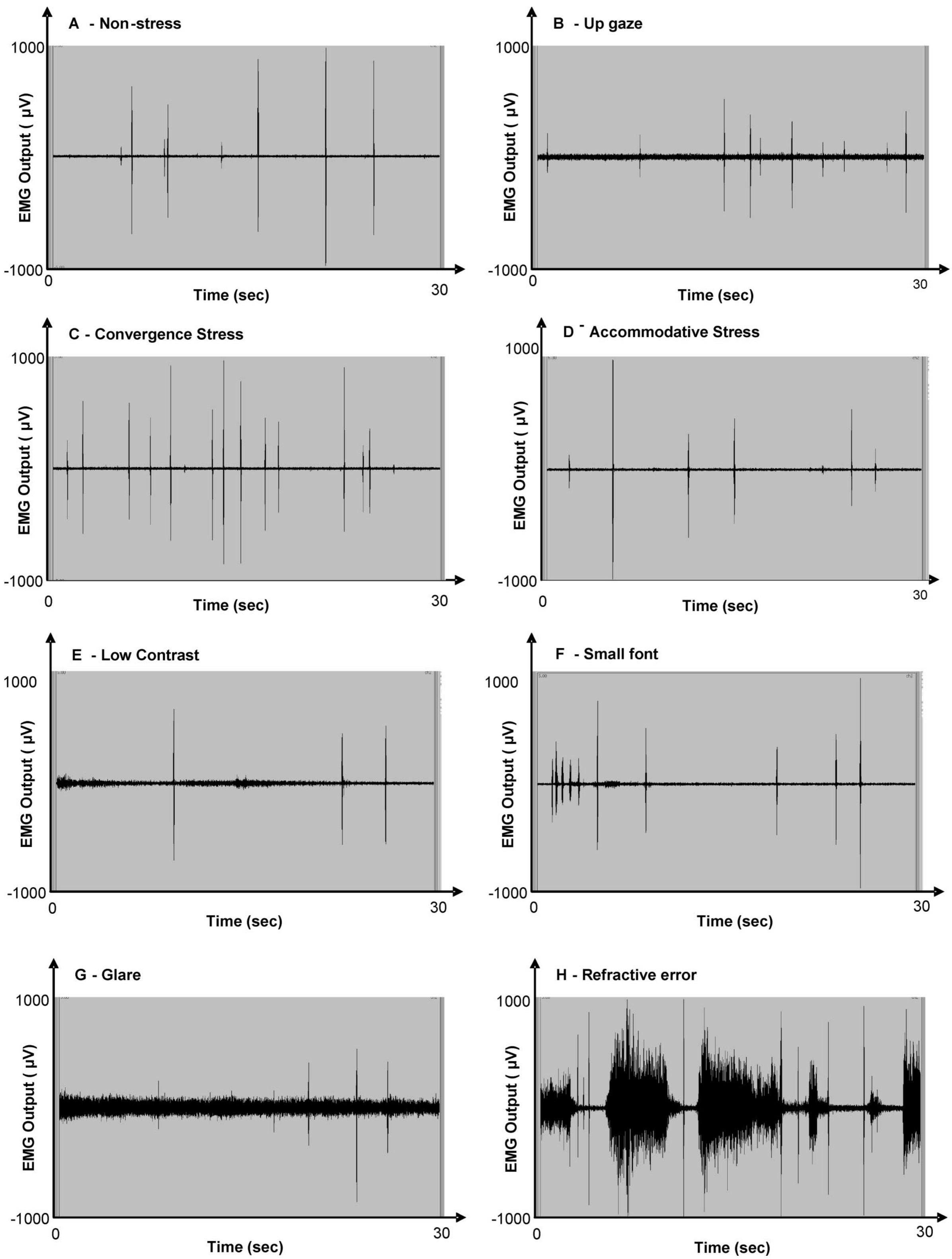

FIGURE 1.

Thirty-second snapshots of EMG traces obtained under different asthenopia-inducing conditions from a representative subject. The x axis represents time and the y axis represents raw EMG values (μV). The peaks in the traces represent blinks. (A) Default nonstress. (B) Up gaze. (C) Convergence Stress. (D) Accommodative Stress. (E) Low Contrast. (F) Small font. (G) Glare. (H) Refractive error.

TABLE 3.
Ratio of palpebral fissure height between asthenopia-inducing conditions and their respective controls

Conditions	Mean ratio	95% CI Lower	95% CI Higher	p
Default nonstress	1.04	1.01	1.07	0.016
Refractive error	0.52	0.42	0.64	<0.001
Glare	0.88	0.85	0.92	<0.001
Low contrast	1.02	0.99	1.04	0.130
Small font	0.98	0.96	1.00	0.061
Up gaze	1.11	1.07	1.15	<0.001
Accommodative stress	1.03	0.99	1.07	0.059
Convergence stress	0.88	0.81	1.13	0.061

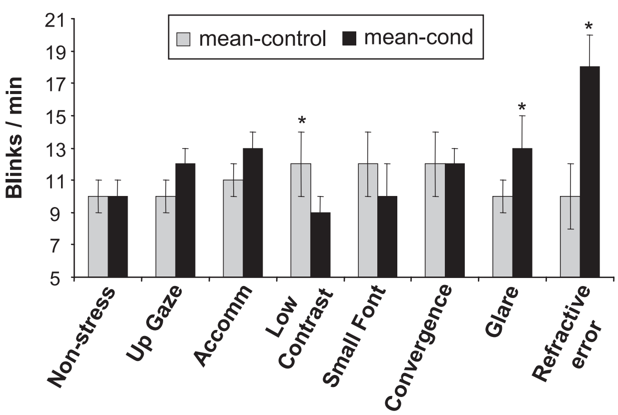

FIGURE 2.
Comparison of blink rate between asthenopia-inducing conditions and their respective nonstress controls. Error bars are standard errors of mean. *Indicates statistically significant differences ($p < 0.05$).

FIGURE 3.
Average electromyography power for the nonstress control conditions that preceded the test conditions, plotted against the order of presentation. Error bars are standard errors of mean.

2. *Group 2:* Low Contrast, Small Font.
   Increased orbicularis oculi EMG, no change in palpebral fissure height, reduced blink rate (for low contrast).
3. *Group 3:* Convergence Stress, Accommodative Stress.
   No change in orbicularis oculi EMG, palpebral fissure height or blink rate.

TABLE 4.
Pearson correlations for the symptoms with calculated internal and external factors

Symptoms	Internal	External	p (for the difference between internal and external correlation coefficients)
Ache	0.92	0.63	<0.001
Muscle strain	0.91	0.55	<0.001
Headache	0.69	0.59	0.034
Double vision	0.47	0.30	0.001
Tired eyes	0.84	0.55	<0.001
Burning	0.52	0.90	<0.001
Irritation	0.65	0.91	<0.001
Dryness	0.52	0.76	<0.001
Tearing	0.45	0.70	<0.001

TABLE 5.
Total discomfort scores for the different conditions

Conditions	Mean score ± SEM
Refractive error	86.45 ± 1.45
Low contrast	63.65 ± 1.86
Convergence stress	50.55 ± 1.97
Small font	49.85 ± 1.98
Glare	45.70 ± 1.91
Up gaze	40.85 ± 1.87
Accommodative stress	38.95 ± 1.64
Default nonstress condition	10.9 ± 3.66

TABLE 6.
Actual time spent and the mean difference between the estimated and actual time spent for the different asthenopia-inducing conditions

Conditions	Actual time spent (min)	Difference (min)	p value
Default nonstress	15.00 ± 0	−0.75 ± 4.77	0.490
Refractive error	7.70 ± 4.34	2.698 ± 6.18	0.066
Glare	13.42 ± 3.51	3.606 ± 7.92	0.056
Low contrast	12.49 ± 3.73	5.357 ± 6.54	0.002
Small font	13.69 ± 2.93	4.663 ± 5.53	0.001
Up gaze	13.00 ± 4.00	3.873 ± 6.56	0.016
Accommodative stress	14.26 ± 2.90	3.342 ± 8.82	0.107
Convergence stress	12.48 ± 4.86	4.175 ± 8.50	0.041

Blink Rate Under Asthenopia-Inducing Conditions

The average measured blink rate during silent picture viewing was 16 blinks/min. Reading during the default nonstress condition decreased the blink rate to 10 blinks/min, which is consistent with previous findings of reduced blink rate during reading and during VDU use compared with relaxed conditions or conversations.[2, 19] It has been suggested that blinking interferes with acquiring visual information during reading and therefore is inhibited.[16]

Group 1: Refractive Error and Glare. Eyelid squint provides a visual benefit for both of these asthenopia-inducing condi-

TABLE 7.
Summary of the results

Conditions	Palpebral fissure height	EMG power	Blink rate	Total discomfort	Perceived duration
Refractive error	**<0.001** (↓)	**0.001** (↑)	**0.005** (↑)	86.45 ± 1.451	0.066 (↑)
Glare	**<0.001** (↓)	**0.001** (↑)	**0.010** (↑)	45.70 ± 1.914	0.056 (↑)
Low contrast	0.130	**0.007** (↑)	**0.035** (↑)	63.65 ± 1.863	**0.002** (↑)
Small font	0.061 (↓)	**0.034** (↑)	0.231	49.85 ± 1.984	**0.001** (↑)
Up gaze	**<0.001** (↑)	**0.001** (↑)	0.157	40.85 ± 1.866	**0.016** (↑)
Accommodative stress	0.059 (↑)	0.088 (↑)	0.084 (↑)	38.95 ± 1.640	0.107
Convergence stress	0.061 (↓)	0.390	0.911	50.55 ± 1.966	**0.041** (↑)

Data are p values. Arrows indicate increase (↑) or decrease (↓) in the mean values for the asthenopia-inducing conditions when compared with their respective nonstress controls. Bold indicates statistically significant results ($p < 0.05$).

tions and both conditions also resulted in increased EMG from the orbicularis oculi and a measured decrease in aperture size (i.e., an eyelid squint response). Eyelid squint reduces the effects of glare (field stop effect) and also improves image quality in the presence of blur because of its aperture stop effect. Eyelid squinting was shown to decrease visual field sensitivity by 1 log unit at about 40° in the superior field and to improve distance visual acuity by 0.24 log MAR units for 3.00 DS myopia.[15] Refractive error (mixed astigmatism +2.00/−4.00 × 180 OU) and glare in this study resulted in the largest orbicularis oculi contraction. The measured concurrent eyelid squint response would have provided visual benefit to the subjects under these conditions.

The video recordings were monocular, from the right eye. It is unlikely that there would be an asymmetry in the squint response under our experimental conditions, as the subjects recruited for this study did not have any ocular abnormalities and the intensity of the asthenopia-inducing stimuli for the two eyes was equal. But if there had been any asymmetry in the squint response, data from this study would not be able to detect it.

Blink rate increased significantly under conditions of refractive error and glare, probably attributable to increased reflex blinking. Blink rate measures during eyelid squinting are probably different for sustained voluntary squint and involuntary squint (under adverse conditions). It has been shown that the sudden introduction of a bright light source in the field of view results in a startle blink reflex.[20] The increased blink rate seen while reading under conditions of intense glare could have been due to reflex blinks.

The amount of eyelid squint required to compensate for the refractive error was high and subjects could not hold the squint throughout the duration of the trial. Figure 1F represents an EMG response trace for the refractive error condition. It can be seen that there are intermittent periods of relaxation between the intense squint efforts. Considering the amount of refractive error used (+2.00/−4.00 × 180), it can be assumed that there would probably be little or no visual acquisition of information during these nonsquint periods within the trial. Blinks typically occurred during these nonsquint periods. Such an increase in blink rate has been previously reported following periods of voluntary squint efforts.[18] Fatigue has also been shown to result in an increase in blink rate.[21] Blink rate was averaged over the entire trial duration. Increased blink rate during the nonsquint periods would have contributed towards the overall increased blink rate measure for the refractive error condition. In retrospect the selected magnitude of blur (+2.00/−4.00 × 180) may have been too large. It is possible that the response to lower blur and glare levels could be quite different.

Group 2: Low-Contrast Text and Small Font Size. These conditions resulted in increased EMG power without an associated decrease in aperture size. Eyelid squint would have improved vision under refractive error and glare, but could not have improved vision with low contrast text or the small font. Because eyelid squint is defined as a reduction in aperture size, these two conditions did not cause eyelid squint, but they did cause an increase in orbicularis oculi contraction. The magnitude of increase in EMG power for these two conditions was lower than for refractive error and glare. Smaller font sizes for the same viewing distance result in lower visual acuity reserves. Low contrast text results in lower contrast reserves. For these two conditions the processes of visual acquisition and interpretation are more difficult.

The increase in EMG power for these two conditions could have been due to an increased visual demand, cognitive demand, or a combination of both. It would be interesting to determine if there would be a reduction in aperture size for prolonged reading sessions under these conditions and also whether the orbicularis oculi muscle would respond to conditions of increased cognitive load not mediated by the visual system.

For the low contrast condition there is a need to extract precise visual information from a compromised environment that cannot be compensated for by the visual system. Unlike the refractive blur, which could be compensated for by the subjects, low contrast resulted in a constantly degraded visual stimulus. Extracting information from this visually degraded stimulus would require increased attention during visual acquisition. Because blinks interfere with the process of acquiring visual information, they might be inhibited under these conditions. The reduction in blink rate in this case seems to be controlled by a central mechanism that inhibits blinks because of the increased visual and cognitive load. Increased attention or cognitive load has been shown to decrease blink rate.[16, 17]

Group 3: Convergence Stress and Accommodative Stress. Convergence stress and accommodative stress [factors that belong to the internal symptom group as defined by Sheedy (2003)] did not result in statistically significant differences in EMG power, palpebral fissure height or blink rate. The p values for EMG power and the palpebral fissure height differences for the accommodative stress condition were close to gaining statistical significance. Eyelid squinting might be beneficial to subjects in the case of accommodative inability or dysfunction. In this study subjects were screened to have at least 10 cycles/min with a ±1.50 DS flipper and normal accommodative amplitude. Lack of increased EMG measures and squint response for the accommodative stress condition in this study suggests that eyelid squinting was not the primary response mechanism used by the subjects in order to compensate for the accommodative demand. The EMG measure from the orbicularis oculi and the eyelid squint response may be altered in the case of subjects who are unable to use their accommodative ability to overcome the demand (in the case of accommodative inability or dysfunction).

The increased EMG response for the up-gaze condition was probably related to maintaining a constant elevated gaze angle required for reading. Looking up by itself did not cause any changes in the EMG response. By virtue of the condition itself, up gaze increased palpebral fissure height compared with the non-stress control.

Orbicularis Oculi Response Mechanisms

The results suggest at least two types of orbicularis oculi responses dependent upon the asthenopia-inducing conditions. The asthenopia-inducing conditions that resulted in increased EMG power from the orbicularis oculi were refractive error, glare, low contrast, small font size and up gaze. Even though all of these conditions result in increased orbicularis oculi contraction only refractive error and glare showed significant eyelid squint. It is compelling that the conditions that result in eyelid squint are those that benefit from it. But it is not clear why there is an orbicularis oculi contraction, of a lesser magnitude and without eyelid squint, for low contrast, small font size and up gaze.

There may be two different mechanisms that cause orbicularis oculi contraction. One mechanism would be stimulated by conditions that can be improved by eyelid squint. The resultant symptoms could be muscular in origin and due to the chronic contraction of the orbicularis oculi or due to secondary effects on blink rate or tear film stability. The other mechanism would be stimulated by generalized stress resulting from a less-than-optimal visual environment that does not benefit from eyelid squint. Asthenopia-inducing conditions have been found to result in myofascial trigger points in the trapezius.[22] This suggests that compromised visual conditions not only result in asthenopia but also lead to a more generalized stress response, which would also manifest in other parts of the body.

Another possibility is that the orbicularis oculi might have reflexively responded to compromised image quality. Even though the initial increase in EMG power for conditions of low contrast and small font might be explained by this reflex mechanism, it probably does not support the consistent increase in EMG power throughout the trial for these two conditions. Data from this study are not sufficient to identify the specific mechanisms.

CONCLUSION

Conditions that resulted in either compromised retinal image quality or less-than-optimal visual environment showed a significant increase in EMG power from the orbicularis oculi when compared with respective nonstress controls. Refractive error and glare, which derive a visual benefit from eyelid squint, resulted in an eyelid squint response and increased blink rate. Low contrast and small font size, which do not benefit from eyelid squint, did not result in aperture size changes and reading low contrast text caused a reduction in blink rate. The mechanism by which these asthenopia-inducing conditions cause orbicularis oculi contraction may be different. Contraction of the orbicularis oculi muscle is caused by the asthenopia-inducing conditions that compromise the visual image and have previously been shown to be primarily associated with the external symptoms of dry eye. In normal subjects accommodative and convergence stress did not cause any significant changes to orbicularis oculi contraction, palpebral fissure height or blink rate. This suggests that probably the cause of symptoms due to these two conditions is mediated by a mechanism that does not involve the orbicularis oculi.

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