Symptoms and Reading Performance with Peripheral Glare Sources

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Abstract

Most of the research into discomfort glare has dealt with studying the effects of luminous objects within 45 degrees of fixation. In this study we investigate effects of a parabolic louvered fixture which created a luminous glare source in the superior visual field extending from 45 degrees to the superior field limit. Thirty subjects each performed thirty minute reading trials on a computer screen under 4 different luminance levels of the glare source, tested in a randomized order. Filtered visors changed the glare luminance without affecting task lighting. Outcome measures were reading speed (words/minute) and symptoms rated on a continuous scale. The symptoms rated were asthenopic (tired eyes, sore eyes, headache), ocular (itchy eyes, dry eyes, watery eyes), visual (blurred vision, double vision), musculoskeletal (neck pain, back pain, shoulder pain) and discomfort from light. Subject rating of light discomfort was strongly related to the luminance level of the glare source ($p<0.0001$). The glare magnitude was also significantly related to asthenopic symptoms ($p=0.012$). Glare magnitude had a significant effect upon asthenopia ($p=0.004$) and musculoskeletal ($p=0.017$) symptoms in the high symptom group but not in the low symptom group, indicating that only those subjects who are more likely to experience and/or report symptoms have such glare induced effects. Accumulated reading time was positively related to asthenopia ($p<0.0001$) and musculoskeletal symptoms ($p<0.0001$), indicating a fatigue effect. This effect was significant for both the high and low symptom groups, indicating a more universal effect of fatigue on these symptoms in contrast to the effects of glare which are more pronounced in those subjects who report more symptoms.

Key Words: vision, glare, symptoms, eyestrain, musculoskeletal, lighting

Introduction

It is well established that highly luminous sources in the field of view can create discomfort glare. Discomfort glare is the sensation of discomfort that is induced by glare sources, not to be confused with disability glare which is a measure of reduced visual function caused by glare. Many of the luminance parameters which induce discomfort glare have been studied and quantified (Guth, 1981). The physiological mechanism by which discomfort is produced is not understood but it has been suggested that it might be related to pupillary fluctuations in size (Fugate and Fry, 1956, and Fry and King, 1975).

It is clear from published research that glare sources closer to the line of sight contribute more to discomfort (Luckiesh and Guth, 1946). Most of the research into discomfort glare, however, has concentrated on studying the effects of luminous objects within 45 degrees of fixation. The effects of discomfort glare from sources between 45 and 90 degrees from the line of sight have received scant attention.

Many office fluorescent lighting systems are designed to reduce or eliminate the discomfort glare. One method is down lighting - usually accomplished by using baffles or louvers to direct the light straight down within a fairly restricted (narrow) angle from perpendicular. The restricted angle of light emergence from the fixture results in areas of high luminance which are more peripheral in the field of view of the room occupants. If, for example, a down lighting fixture were to have an angle of emergence which extended to 30 degrees from the perpendicular, a room occupant with a horizontal gaze could have a glare source 60 degrees from fixation. Although down lighting serves to place the glare source more peripheral to the line of sight compared to more conventional (wide angle) light fixtures, it is possible that it causes discomfort.

In order to test effects of peripheral glare sources upon visual comfort, we established a laboratory environment in which subjects performed a reading task on a computer screen under a large peripheral glare source located from 45 to 90 degrees superior to the line of sight. The luminance of the glare source was controlled by having subjects wear filtered visors.

Methods

The reading task was displayed on a Macintosh IIsi computer with a 12" color monitor. The furniture and computer screen were arranged so that the average eye to screen distance was 60 cm and the center of the screen was located to require about a 12 degree depression of the eyes. The following elements of the computer workstation environment were fixed for all testing: chair and table positions, chair and table height, monitor position, and location of the over head luminaire. Table top illumination of 860 lux (80 fc) was provided by a 2' x 4' 2PMO 332 Optimax Parabolic light control system. The luminaire had 3 four foot fluorescent lamps (GE Trimline 32T8 SP35 RS) with 2900 lumens/lamp output. The candela distribution of the fixture shown in Table 1 was measured with a goniophotometer by Peerless Lighting. The luminaire was 8 feet from the floor and oriented with the 4 foot dimension orthogonal to the line of sight of the subjects. With a design eye height of 47 inches, the far and near edges of the fixture were located to be 45 and 60.3 degrees respectively from the horizontal eye level of the average subject, or 57 to 72.3 degrees from the line of sight when looking at the center of the screen. The width of the luminaire subtended 36 degrees at the subjects eyes. From the subject viewing position, the fixture luminance appeared as a series of horizontal strips of differing luminances due to the structural details of the fixture as detailed in Table 2. The spatially averaged luminance of the fixture was 4500 cd/m^2. Other luminances of relevant objects in the field of view were: screen - 150 cd/m^2, bezel - 80 cd/m^2, immediate visual background (provided by an off-white cloth backdrop) - 50 cd/m^2. Except for the glare source, all luminance ratios were within the lighting guidelines of the Illuminating Engineering Society (Illuminating Engineering Society, 1989).

The luminance of the overhead glare source was varied without changing other luminances in the working area by having the subjects wear visors that were opaque, gray (5% and 27% transmittance) and clear (91%). The resulting spatially averaged luminances of the glare source were 4095, 1215, and 225 cd/m^2 for the gray and clear visors. The luminance of the underside of the opaque visor was 6 cd/m^2. Since the background luminance was 50 cd/m^2 and the background and underside of the visor each occupied about half of visual space, the baseline glare level used for this condition was the average of the two, or 28 cd/m^2 . The visors were supported by headbands which were adjusted to the subject so that they were comfortable and so that the tip of the visor was midway visually between the top of the computer and the bottom of the glare source.

For each trial, subjects read selected stories from the Complete Text of Sherlock Holmes Stories as obtained on a CD-ROM disc (Creative Multimedia Corporation, Portland, OR, 1992) and transferred to Microsoft Word files. Since each subject performed 4 thirty-minute reading trials (one under each peripheral luminance condition), 4 sets of 2 stories each were established for testing purposes. Stories were selected for relative equality in story type, interest level, and length. Stories were displayed in 10 point New York font and 1.5 line spacing. The keyboard was covered with black felt to avoid reflections. Page advance was by depression of a single key which was exposed through a hole in the felt.

Thirty subjects, ages 21 - 39 were screened to have visual acuity of at least 20/20 either without correction or with spectacle correction. Contact lenses were not allowed as a correction during testing. The order of glare level and story set were systematically altered across subjects so that their orders were evenly distributed. Each 30 minute trial was divided into two 15 minute sub-trials for which all physical conditions were identical. All outcome measures, including symptom questionnaire, were obtained after each 15 minute sub-trial. The purpose of the sub-trials was to help mask the intent of the study and to help establish reliability of reading speed and symptoms under each condition After the first 15 minute sub-trial, and before the beginning of the second sub-trial, a meaningless but obvious mechanical switch was switched. The subjects had previously been told, in the protection of human subjects protocol, that effects of light flicker were being tested.

The outcome measures at the end of each sub-trial were the number of words read during each sub-trial and a symptom assessment recorded on a one page score sheet. Twelve named symptoms were on the questionnaire, each with a "0" that could be circled and with a 10 cm horizontal line with "Just Noticeable" and "Very Intense" labeled on either end of the line. Instructions were to "Please indicate which of the following symptoms you are experiencing now by circling 0 for "None" or drawing a vertical line through the horizontal line to rate the intensity of the symptom between the two extremes of "Just Noticeable" and "Very Intense". Symptoms were scored on a scale of 0 to 100 based upon the millimeter location of the vertical slash for each symptom. The symptoms were: tired eyes, sore eyes, itchy eyes, dry eyes, watery eyes, blurred vision, double vision, headache, neck pain, back pain, shoulder pain, and discomfort from lighting. The discomfort from lighting question was not asked of the first 8 subjects. For analysis, tired eyes, sore eyes, and headaches were combined into a group of "asthenopia"; itchy eyes, dry eyes, and watery eyes were combined into a group of "ocular symptoms", blurry vision and double vision were combined into a group of "visual symptoms"; back pain, neck pain, and shoulder pain were combined into a "musculoskeletal symptoms" group.

Results

Analysis Methods

Statistical analysis of the data was by analysis of covariance with SuperANOVA (Abacus Concepts, Inc. Berkeley 1989). The analysis included the following independent variables: subjects (30), trial order # (4), sub-trial # (2), glare level in log luminance (4), and story set (4). The reading speed (words/minute), each of the individual symptoms and each grouped symptom scores were separately treated as dependent variables.

These analyses were performed on the entire subject population (n=30) and also on the 10 subjects with the highest mean symptom ratings across all trials as well as the 10 subjects with the lowest mean symptom ratings.

Symptom Magnitudes

Table 3 displays the mean magnitudes of symptom ratings calculated across all trials - means are presented for all 30 subjects and for the 10 subjects with the highest overall symptom scores and the 10 with the lowest overall symptom scores. The symptom group scores are calculated as a mean of the component symptom scores. Tired eyes, from the asthenopic group of symptoms received the highest scores. Mean scores for light discomfort and for each of the musculoskeletal symptoms were next highest and close in magnitude to one another. The ocular and visual groups of symptoms were generally lower than the other categories - one exception is the high scoring for dry eyes in the high symptom group. All symptoms received higher scores in the high symptom group compared to the low symptom group.

Reading Speed

Figure 1 shows effect of the glare luminance upon the reading speed. Although the reading speed was decreased a small amount with glare magnitude (by about 8% in the low symptom group), it was not statistically significant. Figure 2 shows that the reading speed significantly increased with accumulated reading time (i.e. with subsequent reading trials). The magnitude of reading speed change was much greater for accumulated time (about 13%) than for glare (about -3%). The increased reading speed with time may be due to learned familiarity with the author writing style, reading practice effects, or decreased attention and increased scanning.

Figure 2 also shows that increased reading speed with accumulated reading time showed a similar time course for the high and low symptom subgroups. The group with low symptoms had a higher mean reading speed. This is consistent with the theory that vision and health related symptoms reduced performance of tasks such as reading.

Symptoms and Glare Magnitude

The effect of glare magnitude upon each of the 5 groups of symptoms is shown in Figure 3A. Statistically significant increases in symptoms with increasing glare luminance occurred for the light discomfort rating and for the rating of asthenopia. The most pronounced effect was the increase in perceived light discomfort from glare associated with luminance of the glare source. Glare magnitude was also significantly related to asthenopic symptoms. Tired and sore eyes, but not headaches, were significantly related to glare magnitude.

Figure 3B shows the relationship between glare magnitude and the symptom groups for the 10 subjects with the highest symptom ratings and the 10 subjects with the lowest symptom ratings (the visual and ocular groups did not show significant relationships and are not shown in Figure 3B). Clearly there is a much stronger increase in symptom ratings in those subjects with greater reported symptoms. For the high symptom group the rating of light discomfort showed a substantial and significant increase with increasing luminance of the glare source. For the low symptom group, however, there was a marginal but nevertheless statistically significant increase in the rating of light discomfort. Asthenopia and musculoskeletal symptoms both showed significant increases with increased glare levels for the high symptom group, but not for the low symptom group.

It is interesting to note that for the high symptom group the light discomfort scores increased whereas the musculoskeletal and asthenopic scores decreased between the third and fourth levels of glare (Figure 3B). The decreased musculoskeletal and asthenopic scores may be due to postural or other subject adjustments such as squinting. Further research is planned on this matter.

Of the component asthenopic symptoms, tired and sore eye symptoms were significantly related to glare magnitude and headache was not. Figure 3C shows the effect of glare magnitude upon both tired eyes and sore eyes for the high symptom group and for the low symptom group. It is clear that glare magnitude has a greater effect upon symptoms in the high symptom group than in the low symptom group.

Symptoms and Elapsed Reading Time

Figure 4A shows that symptom scores for the asthenopia and musculoskeletal groups increased significantly with increased accumulated reading time (p=0.0001). The other symptom groups did not approach statistical significance. It is clear that for these 2 groups, symptoms increase with time spent reading. Furthermore, Figures 4B and 4C show that each of the individual symptoms in these 2 groups significantly worsened with time spent reading.

Figure 4D shows that the symptom ratings for the asthenopic and musculoskeletal groups increased significantly with increasing accumulated reading time for both the high and low symptom groups of subjects. The increase in symptoms with increased reading duration is probably related to fatigue which is similar for both the high and low symptom groups. This is in contrast to the effects of glare which only has a solid impact in the high symptom group.

Discussion

It is clear that glare sources located beyond 45 degrees from fixation can cause discomfort. Subject assessment of light discomfort is strongly related to the luminance level of the glare source. This was particularly true for individuals who reported greater levels of symptoms across all symptom groups.

Glare magnitude had a significant effect upon asthenopic symptoms of tired and sore eyes for those subjects with higher levels of rated symptoms - and not in those with lower levels of symptoms. As with ratings of light discomfort, this indicates that subjects who are more prone to report symptoms, or are more sensitive to experiencing symptoms, are the ones who experience glare induced asthenopia. It is reasonable to expect that glare would create symptoms associated with the eyes, although the mechanism is not known.

The high symptom group, and, again, not the low symptom group, also showed a significant increase in musculoskeletal symptoms with increased glare level. It is possible that glare elicits musculoskeletal symptoms by increased muscular tension, induced posture change, or light discomfort may be a potentiator upon other areas of discomfort.

All groups of subjects showed increased reading speed and increased asthenopic and musculoskeletal symptoms as they read longer. These effects were similar for both the high and low symptom groups of subjects. This suggests a more universal effect of longer reading periods, probably via fatigue, upon asthenopic and musculoskeletal symptoms. This is in contrast to the effect of glare which has a much stronger impact on subjects who are more likely to report symptoms.

Acknowledgment

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Table 1. Candela distribution of luminaire.

Angle from Vertical	0.0 degrees	22.5 degrees	45.0 degrees	67.5 degrees	90 degrees
0.0	2949	2949	2949	2949	2949
5.0	2941	2962	2976	2976	2966
15.0	2811	2912	3148	3330	3379
25.0	2604	2805	3330	3597	3688
35.0	2274	2782	3138	3300	3237
45.0	1545	1892	1894	906	786
55.0	191	266	230	108	46
65.0	10	10	10	9	9
75.0	5	6	4	5	4
85.0	1	1	1	1	1
90.0	0	0	0	0	0

Table 2. Luminance of overhead fixture as viewed from nominal position of eye. Due to fixture design the luminances were essentially horizontal strips of different luminances - width was 36 degrees.

Angle from Horizontal Gaze	Angle from Screen Center	Luminance
from 45 degrees	from 57 degrees	
to 46.2	to 58.2	2000 cd/m^2
to 47.4	to 59.4	150
to 48.7	to 60.7	2000
to 50.8	to 62.8	7000
to 51.5	to 63.5	150
to 52.9	to 64.9	3000
to 56.0	to 68.0	9000
to 56.9	to 68.9	150
to 58.5	to 70.5	3500
to 59.4	to 71.4	9500
to 60.3	to 72.3	3500

Table 3. Average symptom score, on a scale of 0 to 100, for each symptom and symptom group.

	All Subjects	Hi Symptom Group	Lo Symptom Group
Asthenopia Group	**9**	**16**	**3**
tired eyes	20	34	7
sore eyes	6	11	1
headache	1	2	0
Ocular Group	**4**	**9**	**1**
itchy eyes	2	4	1
dry eyes	8	18	1
watery eyes	2	5	0
Visual Group	**2**	**4**	**1**
blurry vision	3	8	1
double vision	0	0	0
Musculoskeletal Grp	**5**	**8**	**1**
back pain	5	10	0
neck pain	6	11	1
shoulder pain	4	4	2
Light Discomfort	**6**	**12**	**1**

Figure legends

Figure 1 - The effect of glare magnitude upon reading speed for all subjects (n=30) and for the 10 subjects with highest overall symptom scores and for the 10 subjects with lowest overall symptom scores. ANOVA significance levels indicated.

Figure 2 - The effect of accumulated reading time upon reading speed for all subjects (n=30) and for the 10 subjects with highest overall symptom scores and for the 10 subjects with lowest overall symptom scores. ANOVA significance levels indicated.

Figure 3A - The effect of glare magnitude upon group symptom rankings for all subjects (n=30). ANOVA significance levels indicated.

Figure 3B - The effect of glare magnitude upon selected group symptom rankings for the 10 subjects with highest overall symptom scores and for the 10 subjects with lowest overall symptom scores. ANOVA significance levels indicated for the high symptom group. For the low symptom group, only light discomfort was significant (p=0.0036).

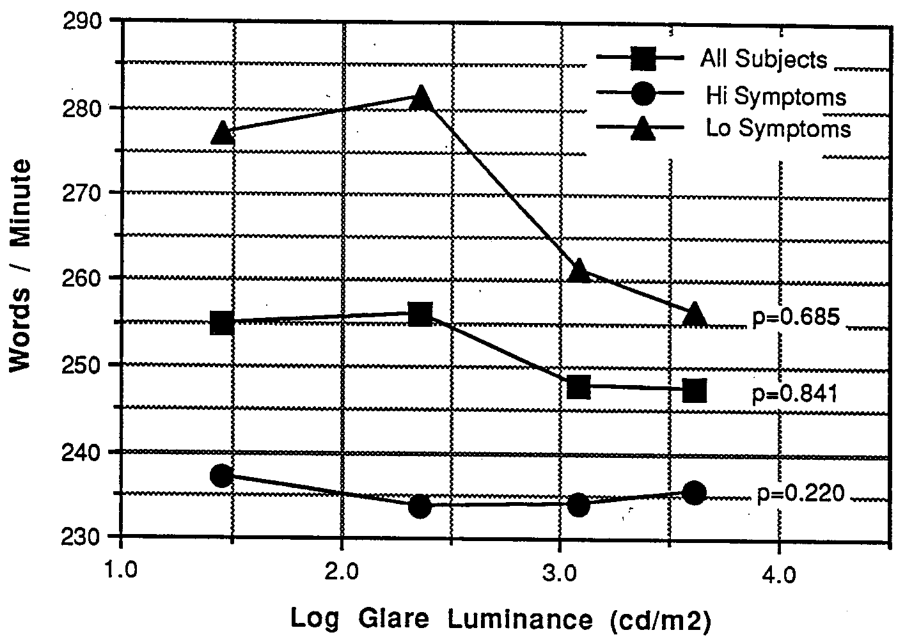
Figure 3C - The effect of glare magnitude upon tired and sore eyes for the 10 subjects with highest overall symptom scores and for the 10 subjects with lowest overall symptom scores. ANOVA significance levels indicated.

Figure 4A - The effect of accumulated reading time upon group symptom scores for all subjects (n=30). ANOVA significance levels indicated.

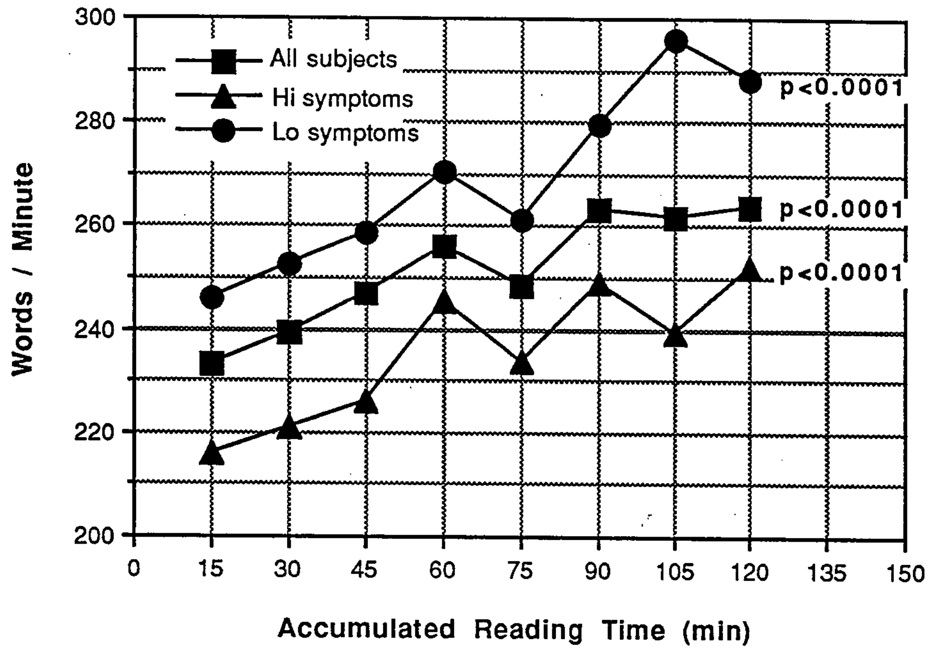
Figure 4B - The effect of accumulated reading time upon individual asthenopic symptom scores for all subjects (n=30). ANOVA significance levels indicated.

Figure 4C - The effect of accumulated reading time upon individual musculoskeletal symptom scores for all subjects (n=30). ANOVA significance levels indicated.

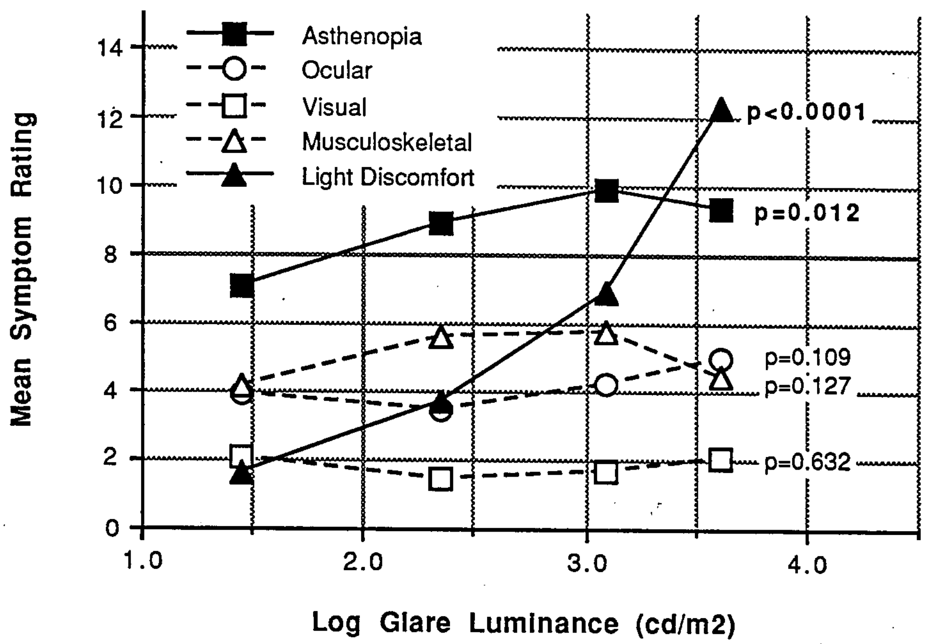
Figure 4D - The effect of accumulated reading time upon asthenopic and musculoskeletal symptoms for the 10 subjects with highest overall symptom scores and for the 10 subjects with lowest overall symptom scores. ANOVA significance levels indicated.



290
280
270
260
250
240
230
Words / Minute
All Subjects
Hi Symptoms
Lo Symptoms
p=0.685
p=0.841
p=0.220
1.0
2.0
3.0
4.0
Log Glare Luminance (cd/m2)

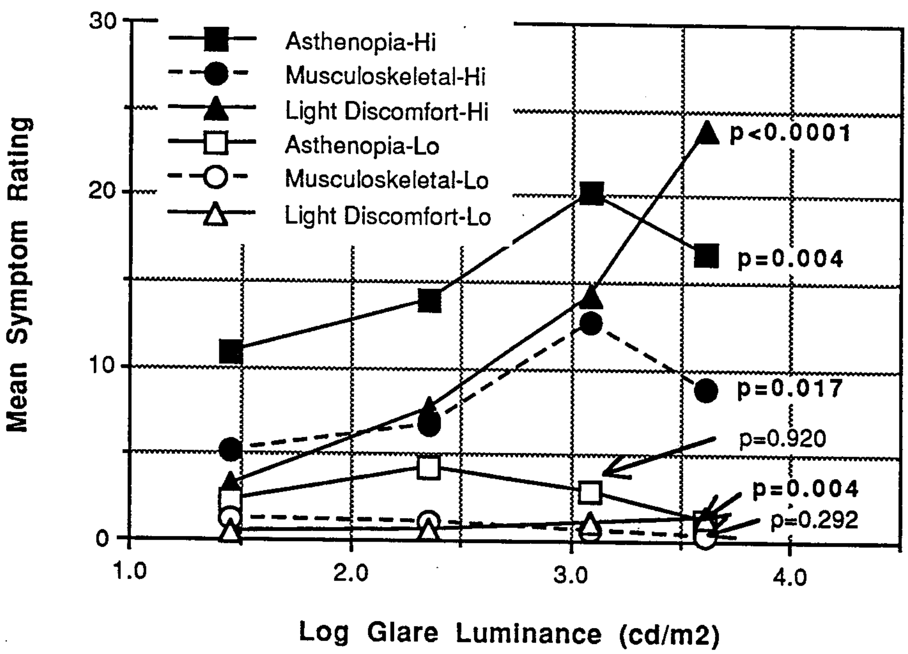


All subjects
Hi symptoms
Lo symptoms
p<0.0001
p<0.0001
p<0.0001
Words / Minute
300
280
260
240
220
200
0
15
30
45
60
75
90
105
120
135
150
Accumulated Reading Time (min)



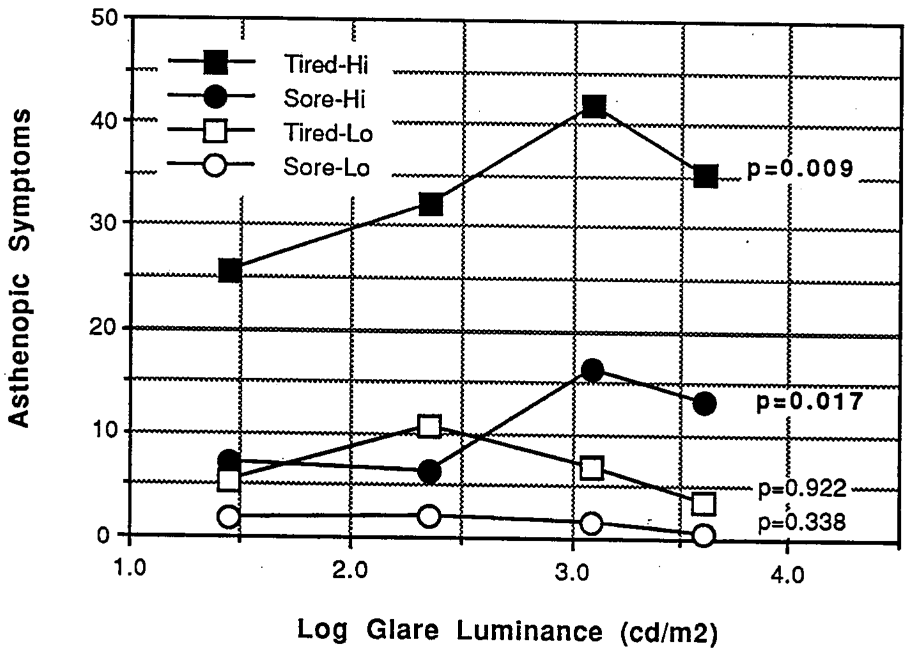
Asthenopia
Ocular
Visual
Musculoskeletal
Light Discomfort
Mean Symptom Rating
14
12
10
8
6
4
2
0
1.0
2.0
3.0
4.0
Log Glare Luminance (cd/m2)
p<0.0001
p=0.012
p=0.109
p=0.127
p=0.632

3A

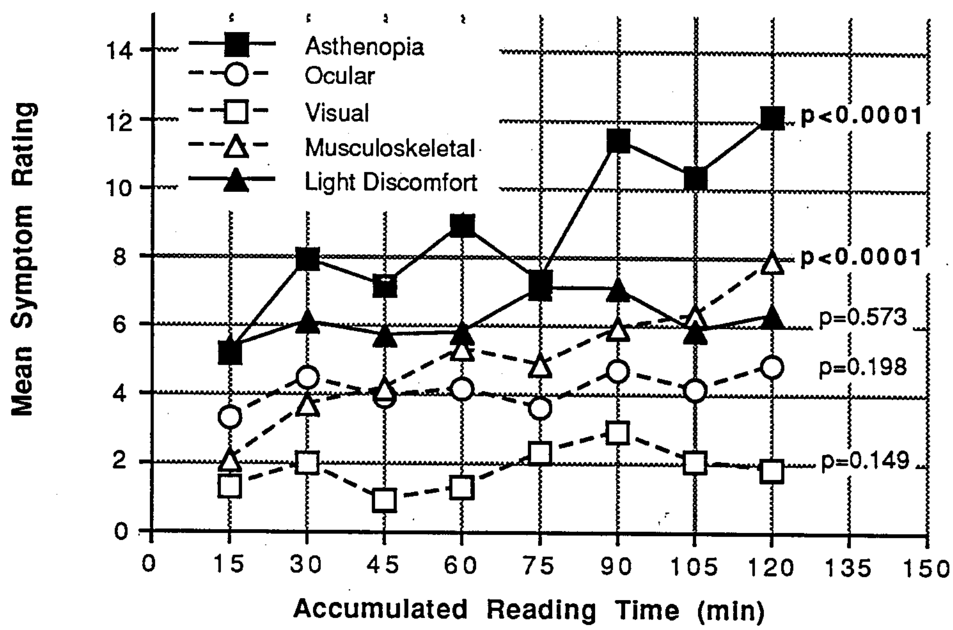


30
20
10
0
Asthenopia-Hi
Musculoskeletal-Hi
Light Discomfort-Hi
Asthenopia-Lo
Musculoskeletal-Lo
Light Discomfort-Lo
p<0.0001
p=0.004
p=0.017
p=0.920
p=0.004
p=0.292
1.0
2.0
3.0
4.0
Mean Symptom Rating
Log Glare Luminance (cd/m2)

3B

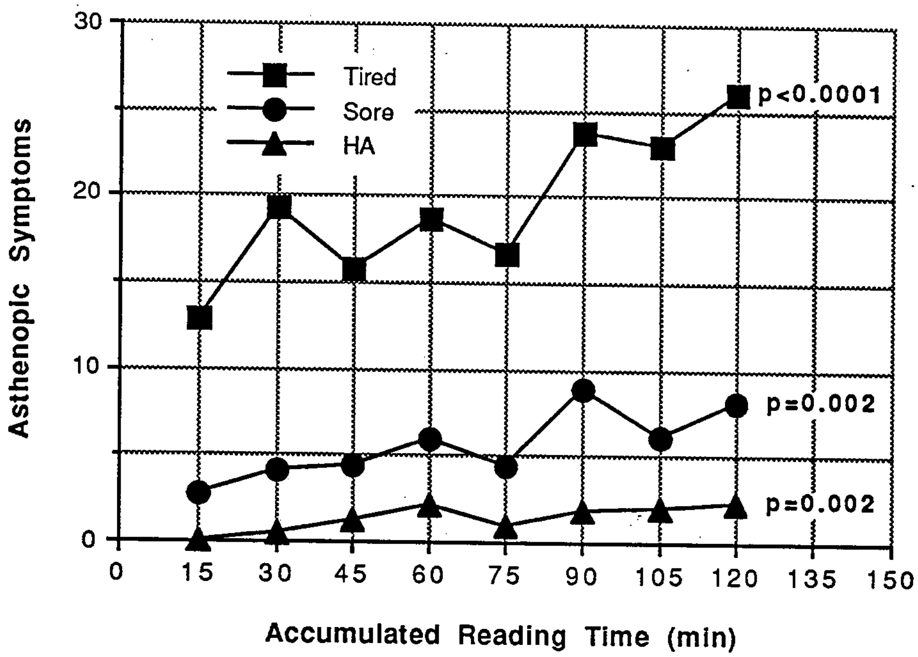


Asthenopic Symptoms
50
40
30
20
10
0
Tired-Hi
Sore-Hi
Tired-Lo
Sore-Lo
p=0.009
p=0.017
p=0.922
p=0.338
1.0
2.0
3.0
4.0
Log Glare Luminance (cd/m2)



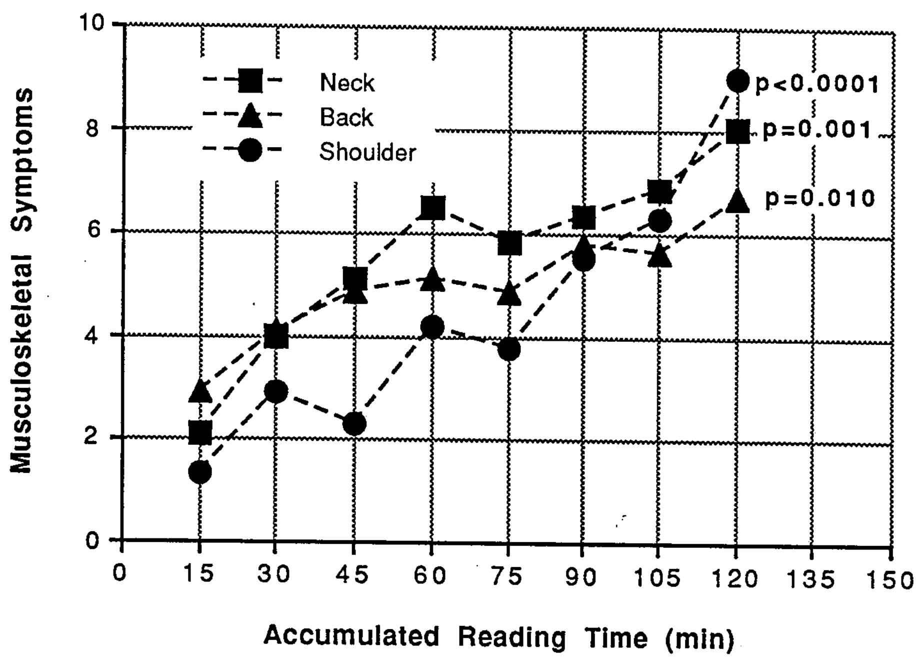
Asthenopia
Ocular
Visual
Musculoskeletal
Light Discomfort
p<0.0001
p<0.0001
p=0.573
p=0.198
p=0.149
Mean Symptom Rating
0
2
4
6
8
10
12
14
0
15
30
45
60
75
90
105
120
135
150
Accumulated Reading Time (min)

4A



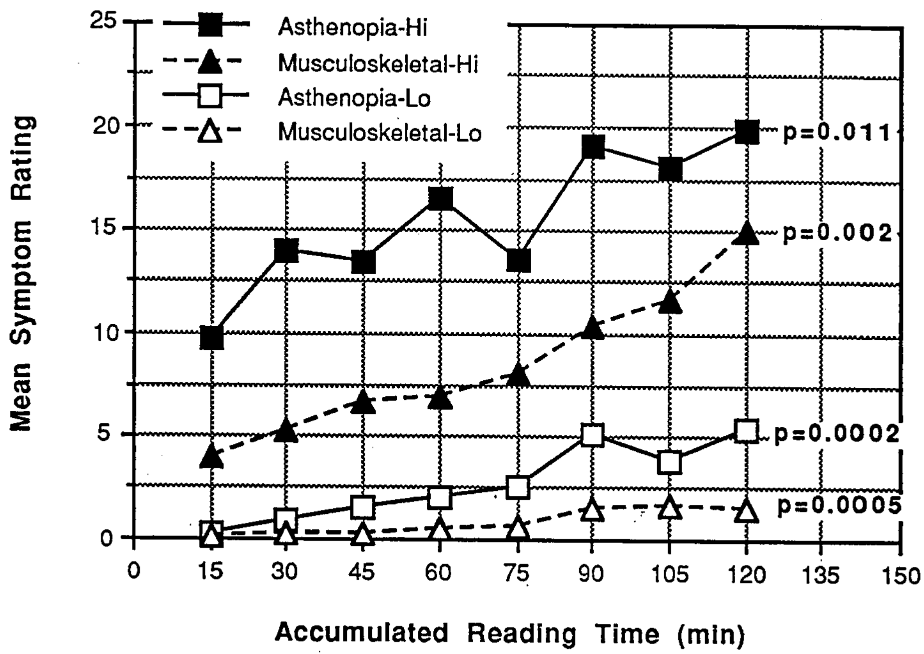
30
20
10
0
Asthenopic Symptoms
Tired
Sore
HA
p<0.0001
p=0.002
p=0.002
0
15
30
45
60
75
90
105
120
135
150
Accumulated Reading Time (min)

4B



Musculoskeletal Symptoms
10
8
6
4
2
0
Neck
Back
Shoulder
p<0.0001
p=0.001
p=0.010
0
15
30
45
60
75
90
105
120
135
150
Accumulated Reading Time (min)

4c



Asthenopia-Hi
Musculoskeletal-Hi
Asthenopia-Lo
Musculoskeletal-Lo
p=0.011
p=0.002
p=0.0002
p=0.0005
Mean Symptom Rating
0
5
10
15
20
25
0
15
30
45
60
75
90
105
120
135
150
Accumulated Reading Time (min)

4D