Comparison of Flat and Curved Monitors: Eyestrain Caused by Intensive Visual Search Task

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Abstract
Twenty-seven observers performed intensive visual search tasks with curved and flat monitors. Based on a 22-item eyestrain questionnaire, fewer subjects reported eyestrain, difficulty-to-focus and blurred-vision symptoms with a curved monitor than with a flat monitor. Fewer subjects had reduced saccade peak speed following the curved monitor use.

Author Keywords
Eyestrain; visual search; binocular accommodative function.

1. Objective and Background
Symptoms of eyestrain are frequently reported, presumably due to the large increase in time spent viewing electronic displays. The various vision problems associated with using computers is defined by the American Optometric Association as computer vision syndrome (CVS) [1]. It has been reported that up to 90% of computer users experience CVS symptoms [2]. The most common symptoms of CVS are eyestrain, headaches, ocular discomfort, dry eye, diplopia, or blurred vision [1, 3].

Due to the visual discomfort, CVS has an economic impact. Productivity is reduced as a result of increased errors, more frequent breaks, and workers compensation costs from work related musculoskeletal injuries associated with computer use. Minimizing symptoms that reduce efficiency will provide a financial benefit [1].

CVS symptoms may be reduced by treating uncorrected refractive error, accommodative/vergence anomalies, and dry eye [1]; allowing breaks; and optimizing ergonomic positioning [3]. Better display designs can potentially be another approach to address CVS. Curved TVs and monitors are available on the market, and have been claimed to reduce visual fatigue [4]. However, there has not been sufficient evidence to support such claims. The purpose of this study was to determine whether symptoms of CVS could be lessened with a curved monitor than a flat monitor. We also measured the effects of the monitors on visual functions.

2. Methods
Participants performed an intense visual search task on curved and flat monitors. A questionnaire, eye movement recordings, and convergence and accommodative function tests were administrated before and after the search task. Each participant was tested with one of the monitors in the first visit and the other monitor in second visit, at least one day later.

Monitors: A Samsung 34” curved monitor (S34E790C, radius 3 meters) and a Samsung 34” flat monitor were used for this study. The brightness of the monitors was 280 cd/m2, and 260 cd/m2, respectively. The resolution for both monitors is 3440×1440. Participants sat 40cm from the monitors, and the monitors spanned about 92° horizontally.

Visual Search Tasks: The participants performed 2 tasks. In the first task, they searched for a given target within a real world image using a mouse cursor to select the target. There were a total of 300 images including faces, indoor scenes, and object collections. The second task involved searching for a target image among multi-page search results returned by a Google image search using a keyword, such as “zebra” (Figure 1). In total, participants searched for 12 targets among 7089 returned images. To minimize the effect of memory, each participant was given different targets in the 2 visits. The orders of monitor and search targets were counter-balanced across participants. Search time was recorded to quantify search performance.

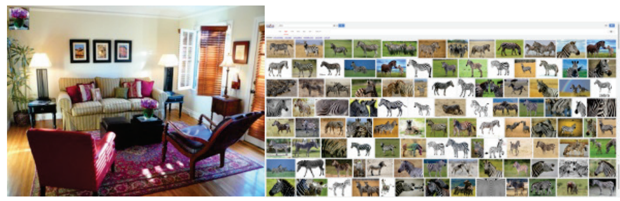

Figure 1. On the left is 1 of the 300 search images. Assigned search target is shown in the upper left corner. On the right is an example of the multi-page image array returned by Google when given the keyword, “zebra”. Targets were given in a different window not shown here.

Questionnaires: Participants were administrated a discomfort questionnaire immediately before and after the visual search experiment. The questionnaire included 22 items: General discomfort, Overall fatigue, Headache, Eyestrain/ache, Difficulty focusing (eye), Salivation increasing, Sweating, Nausea, Difficulty concentrating, Fullness of head, Blurred vision, Dizziness with eyes open, Dizziness with eyes close, Vertigo, Stomach awareness, Burping, Eyes feel tired, Pulling feeling around eye, Double vision, See objects on screen move/jump, Eyes feel itchy, Eyes feel scratchy. These items were categorized into 4 categories: asthenopic (eye strain), ocular-surface related, visual, and motion sickness.

Binocular Accommodation Tests: Binocular accommodative functions were measured in each visit before the pre-search questionnaire and repeated after the post-search questionnaire. The assessment included 15 clinical tests for: phoria, convergence, accommodative functions etc. Based on these tests, diagnosis for 6 possible binocular deficiencies were assigned [5]: Convergence insufficiency (CI), Convergence excess (CE), Fusional version dysfunction (FVD), Accommodative insufficiency (AI), Accommodative excess (AE), and Accommodative infacility (A_infacility). Changes in these diagnoses were used in data analysis..

Eye Movement Recording: Eye movements of each participant were measured using a 500Hz eye tracker (EyeLink II), before and after the visual search task. During the eye movement recording session, participants were instructed to make 20° leftward (n=20) and downward (n=20) saccades from fixation to a target. Saccade latency, duration, and peak speed were measured. In an additional free viewing task, the eye tracker counted the number of blinks as the participants viewed 6 real-world images for 1 minute in total.

Participants: Twenty-seven normally sighted participants (age 18 to 35) completed the study. Their near visual acuities (with habitual correction when needed) were 20/20 or better.

3. Results

Visual Search: On average, the visual search task took about 55 minutes to complete. Overall, there was no significant difference in search performance between curved and flat monitors (p=0.89, paired t-test).

Eyestrain Questionnaire: After visual search, 26 out of 27 participants reported at least one discomfort symptom for either or both monitors. Comparing participants' reports before and after the visual search task, overall most of the discomfort symptoms increased (20 out of 22) and only one decreased. The numbers of increased cases for all symptoms are reported in Figure 2. According to a proportion test, a difference of 3 cases (dashed line in Figure 2) is significantly different from no change. As can be seen, 9 of the 22 symptoms were above this level: general discomfort, overall fatigue, eyestrain, difficulty focusing, difficulty concentrating, blurred vision, eyes feel tired, pulling feeling around eyes, and eyes feel scratchy. While for the other symptoms were reported after the search task the increase was not statistically significant.

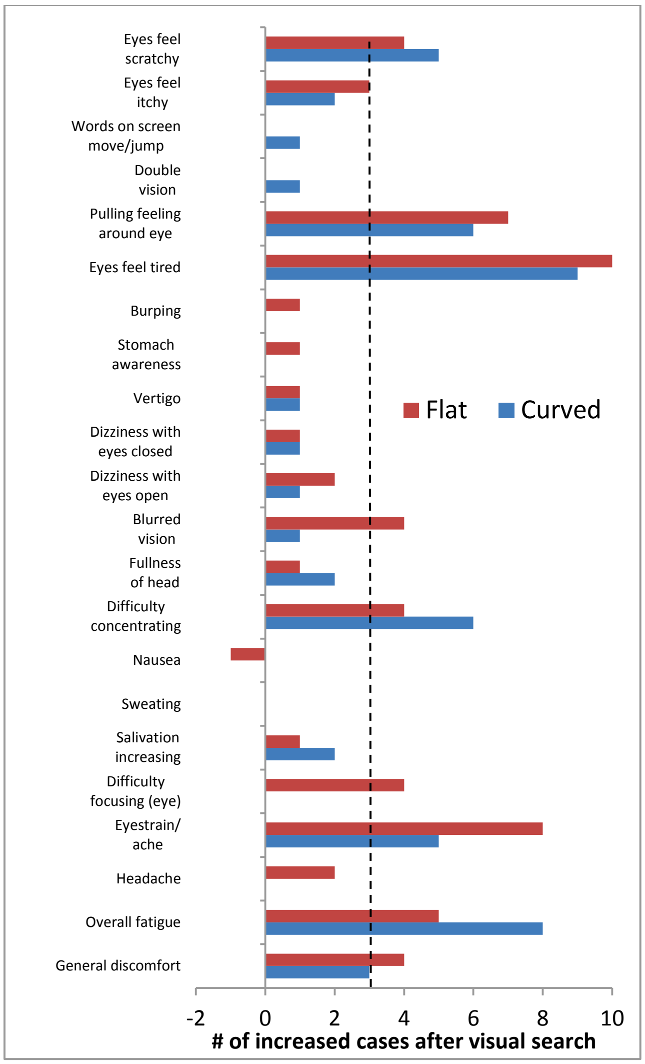

Figure 1. Out of 22 symptoms, 9 symptoms significantly increased (beyond the dashed line, which indicates significance) after visual search for either or both monitors.

Based on the number of symptoms each participant reported pre- and post-search, a paired t-test did not find a statistically significant difference between the two monitors. Figure 3 shows the number of participants who reported worsening symptoms after search for the 9 symptoms mentioned above. The proportion test found that significantly more participants reported some worsening symptoms with the flat monitor than the curved monitor (indicated by star markers in Figure 3): eyestrain (4 more, p=0.019), difficulty to focus (4 more, p=0.019), blurred vision (3 more, p=0.037), and eyes feel tired (3 more, p=0.037). On the other hand, overall fatigue was reported by more subjects for the curved monitor than the flat monitor (3 more, p=0.037, indicated by a cross marker in Figure 3).

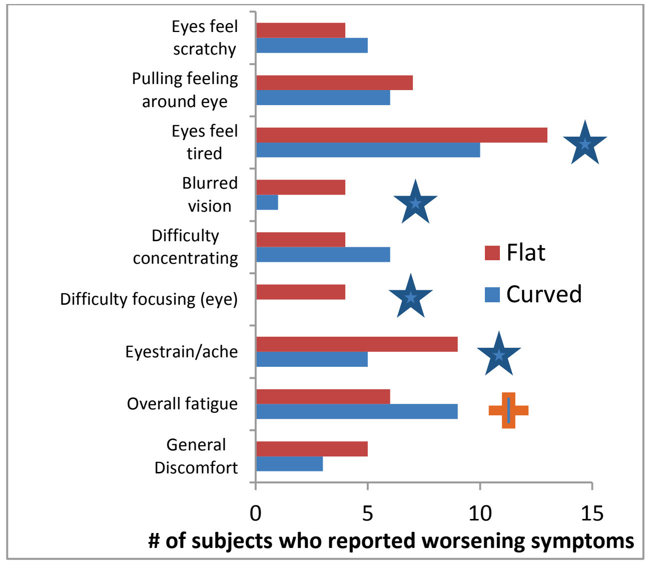

Figure 2. The 4 star markers indicate symptoms that worsened in significantly more participants with the flat monitor than the curved one. The cross marker indicates that overall fatigue (not eye specific) symptom worsened in significantly more subjects with curved than the flat monitor.

Eye Movements: We did not find any significant difference between flat and curved monitors in saccadic latency, saccadic duration or number of blinks. The only significant difference found was in peak speed of horizontal saccades: more participants had slower horizontal saccadic peak speed after the search task with the flat monitor (p=0.004).

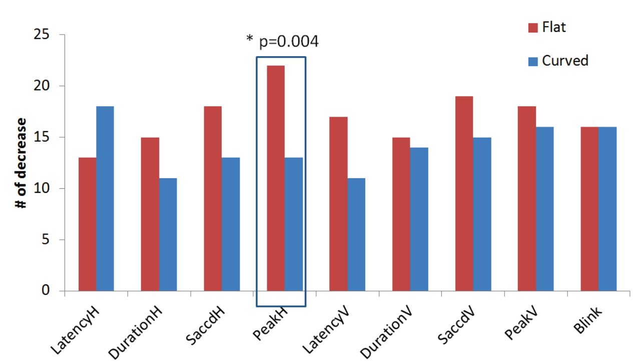

Figure 3. Among the 9 eye movement parameters analyzed including: latency, speed and blinks, only horizontal saccade peak speed was significantly different between the two monitors. More participants had slower horizontal saccadic peak speed after visual search with the flat than with the curved monitor.

Convergence and Accommodative Functions: The convergence and accommodative function testing examined participants' convergence and accommodation capabilities or deficiencies. These tests not only check convergence and accommodation separately, but also check combined (binocular) convergence and accommodation performance. In order to clearly see a target, the eyes need to turn towards the object and focus properly for its distance.

Among the 26 participants who reported symptoms after the search task for either or both monitors, 14 were diagnosed with at least one binocular accommodative dysfunction either pre- or post-search, and the other 12 were not found to have any dysfunction. The only one participant who did not report any symptom was not found to have any dysfunction.

Figure 5 shows the number of participants who were diagnosed with binocular accommodative dysfunctions and also reported eyestrain, difficulty focusing, or blurred vision symptoms after the search task. There seems to be a pattern that they were more likely to have accommodative dysfunctions, namely, AI, AE and A_infacility. Interestingly, for those 3 dysfunctions, the curved monitor seemed to be associated with fewer cases than the flat monitor, but the difference did not reach statistical significance.

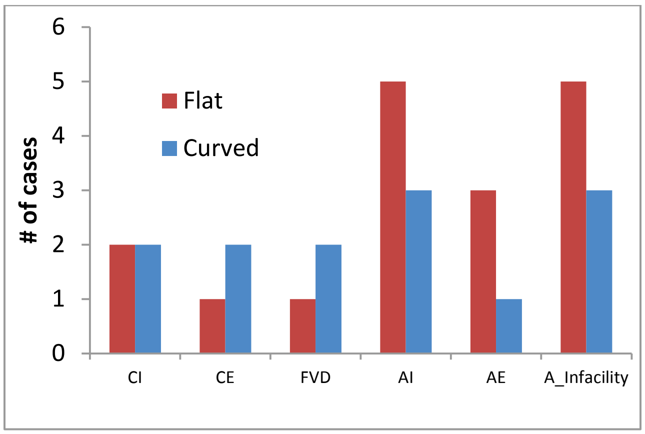

Figure 4. Accommodative dysfunctions (AI, AE, A_infacility) might be more common in participants who reported post-search eyestrain, difficulty focusing and blurred vision than convergence dysfunctions. The curved monitor seemed to be associated with fewer cases for these 3 dysfunctions than the flat monitor, but the difference was not significant.

4. Impact

Our preliminary results showed that the visual search task used in this study was intense enough to cause notable eye discomfort within a short period of time (nearly one hour on average) for almost all participants. This is consistent with numerous studies and user complaints about CVS. Since computer users can easily spend many hours a day engaging in intense tasks on electronic displays, the prevalence of eye discomfort could be even greater. Curved monitors have been suggested as one solution to address the problem. Anecdotal evidence based on very short exposure (0.5-2 minutes) might suggest that users felt "more comfortable" with curved monitors than flat ones [6]. However, it is unlikely that observers experienced CVS symptoms following such a short exposure. Their reports probably reflect some visual appeal of novel curved monitors. Our study evaluated the curved monitor based on commonly used clinical tests and symptoms.

We did not find significant differences in eye discomfort symptoms between flat and curved monitors based on comparison of group means or medians. Based on the proportion test, however, the questionnaire data did show that fewer observers reported worsening eyestrain, difficulty focusing, blurred vision, and eye tiredness symptoms following the search task with the curved monitor than with the flat one. This could suggest that the curved monitor might be more comfortable for <u>some</u> display users.

We did not find evidence from eye movements and convergence-accommodation tests to suggest what might account for fewer complaints for the curved monitor, and what types of users might benefit from curved monitors if the benefits are real. A possibly higher percentage of accommodative dysfunctions (AI, AE, A_infacility) among reporters of symptoms could suggest that accommodation may be a factor for discomfort in our study. It should be kept in mind that the difference in viewing distance at the monitor edge between the two monitors was very small (accounting only for about 0.1diopter in accommodation demand). It is not clear how such a small difference might play a role. Also, a fair number of observers reported symptoms but did not have any dysfunction. Nevertheless, these findings warrant further investigation.

It is unclear why the curved monitor was associated with more overall fatigue, while some eye-specific symptoms were less at the same time. This was inconsistent with the "general discomfort" question, and no other items in our questionnaire might suggest overall fatigue with the curved monitor would be high.

It has been previously reported that greater eyestrain and more reading errors were associated with electronic displays, when compared to paper copies [7]. When convergence and accommodative insufficiencies, which were found to be associated with eyestrain symptoms [8], were successfully treated in school-age children, their academic performance improved [9]. In this study, we did not find a difference in search performance between the two monitors. This may be because the difference in symptoms was not large enough to impact visual search during the short experiment.

Taken together, the effect of a curved monitor on CVS and task performance needs to be evaluated in larger-scale, longer-term follow up studies.

5. Acknowledgement

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6. References

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