Elisabeth M. Fine, Eli Peli, and Angela T. Labianca, Image Enhancement of Scrolled Text, in Vision Science and Its Applications, 1994 Technical Digest Series, Vol. 2 (Optical Society of America, Washington, DC, 1994), pp. 254-257.

Image Enhancement of Scrolled Text

Elisabeth M. Fine[1,2], Eli Peli[2], and Angela T. Labianca[2]

1. Northeastern University Dept. of Psychology, 125 Nightingale Hall, Boston, MA 02115
2. The Schepens Eye Research Institute, 20 Staniford St., Boston, MA 02114

Introduction

The use of image enhancement for the visually impaired was first proposed by Peli and Peli in 1984. Today, the technology to implement image enhancement techniques in real-time exists. We tested the use of this technology in the reading of scrolled text. The purpose of this study was to determine if this enhancement algorithm would increase impaired observers' ability to read scrolled text. This is particularly important because Lawton et al. (1993) have shown substantial increases in reading rate for scrolled text enhanced with spatial filtering in a similar patient population.

Experiment 1

This experiment was designed to determine if the contrast enhancement found to improve perception of details in moving scenes, as well as to increase the appreciation of motion videos among low vision subjects (Peli, Fine, and Pisano, 1993), would also increase their reading speed for moving text. In addition, we sought to replicate Lawton's (1989; 1992) finding of a 200 to 400% increase in reading speed using spatial filtering.

Methods

Subjects

Forty one subjects, with acuity ranging from 20/100 to 20/800, in most cases due to central scotoma, were run, of which 31 were included in the final analysis. Subjects were excluded from the final analysis if they left the study for any reason (some found the reading task too demanding), their first language was other than English, or due to Experimenter error.

Apparatus

Sentences were presented on a modified Horizon Electronic Digital Magnifier. Contrast enhancement was accomplished using the DigiVision device design to implement the enhancement algorithm of T. Peli and Lim (1982). Detail, contrast, and background were set to produce text that was visually similar to the example found in Lawton (1992), for which she found the largest increases in reading rate.

Materials and Design

Forty eight sentences of 55 characters each, from the MNRead test developed and previously used by Legge et al. (1985) were typed in Monaco 18 font, scanned and stored in the Horizon. For presentation, each character was magnified to a height of 40 mm. At a seating distance of 40 cm, the width of each character subtended 6.32 deg, on average. Letters were presented in reverse polarity (white characters on a dark background). Sentences were presented in the same order for all subjects. The order of presentation of enhanced or unenhanced text was counterbalanced across subjects.

Procedure

Subjects' acuity was measured using a standard Snellen chart. This was used to classify subjects as near threshold or above threshold. Those subjects for whom our 6.32 deg letters were at least five times acuity threshold were classified as above threshold (n = 21). All others were classified as near threshold (n = 8). This categorization was based on Legge's (1991) finding that reading rate is maximized when letter size is five times acuity threshold.

Subjects were asked to read the sentences out loud. The first sentence was presented at 10.2 words per minute (wpm). For each sentence that was correctly read (with fewer than two errors) the rate was increased by 10.2 wpm. When two or more errors were made, the current rate was repeated. If fewer than two words were read incorrectly, testing continued. If two or more errors were again made at this rate, testing for that condition was complete. The maximum rate at which each subject read a sentence with fewer than two errors was defined as his/her maximum reading rate. Following a short break, testing was repeated using the other display format.

Results and Discussion

The average reading rate for text without enhancement was 112.5 wpm with a range of 10.2 to 194.4. For enhanced text, the average was 120.1 wpm with a range of 20.5 to 204.6. This difference was significant across subjects [$F(30,1) = 4.49$, $p = .042$].

Because of the large range of reading rates for unenhanced text, we also looked at the percent of increase in maximum reading rate with enhancement for each subject. We believe this measure better represents the differences across conditions. In fact, we found a strong correlation between reading rate for unenhanced text and percent improvement [$r = -.463$, $p = .01$]. Overall, our subjects showed a 13.5% increase in reading rate with enhancement, a significant improvement [$t(30) = 2.3$, $p = .029$].

We also calculated the average change in reading rate for the near and above acuity threshold groups separately. Two subjects were excluded from this analysis because their acuity could not be accurately measured. The above threshold group showed an 8.5% (SD = 24.7) increase in maximum reading rate with enhancement [$t(20) = 1.54$, $p = .14$]; the near threshold group improved by 27.4% (SD = 46.2) with enhancement [$t(7) = 1.57$, $p = .16$]. The difference in improvement between the two groups also did not reach significance [$F(1,27) = 1.87$, $p = .18$]. The lack of statistical significance both for the comparison between the groups, as well as the improvement in reading rate for the near threshold group, was likely due to the small number of subjects and the large standard deviation in that group. It may be that this large variability in the near threshold group is unavoidable. Legge (1991) showed that reading rates increased steeply up to five times acuity threshold. For some of the subjects in our near threshold group, the unenhanced letters were quite close to five times threshold, while for others they were well below this standard.

The enhancement algorithm produced a dark annular region around the letters, thereby increasing the contrast. It also increased the size of the enhanced letters. This increase in letter size may have resulted in the large increases in reading rate for those subjects reading unenhanced characters less than five times their acuity threshold. The steep increase in reading rate up to five times threshold character size could lead to the large increases our near acuity threshold group showed due simply to the increased size of the enhanced characters. Experiment 2 was designed to assess this possibility.

Experiment 2

Methods

Subjects

Fourteen subjects, from the same population used in Experiment 1 were used here.

Apparatus

In addition to the apparatus used in Experiment 1, we also used a Mentor B-VAT for acuity testing.

Materials and Design

An expanded set of 117 sentences from the same source as Experiment 1 were used. Subjects were presented with text in three formats: small unenhanced (SU), small enhanced (SE), and large unenhanced (LU). The LU characters were the same size as the SE characters. For this Experiment, the SU characters were 34 mm high; the LU characters were 40 mm. Sentences were presented in the same order for all subjects. The order of presentation condition was counterbalanced across subjects.

Procedure

Subjects' acuity was measured using the Mentor B-VAT. We have not looked separately at the near and above acuity threshold groups for this study due to the limited number of subjects we have been able to run to date. Testing procedures were the same as in Experiment 1 with the addition of the new presentation format.

Results and Discussion

There was a significant effect of presentation format on maximum reading rate [$F(13,2) = 6.55$, $p = .005$]. For the SU text the average reading rate was 121.30 wpm (range 10.2 - 194.4); for LU 114.72 (range 10.2 - 184.1); for SE 135.9 (range 10.2 - 204.6). The maximum reading rate for the SE text was significantly greater than both the SU and LU text [$t(13) = 2.46$, $p = .03$ and $t(13) = 2.87$, $p = .01$, respectively].

We again looked at the percent difference in reading rate for the enhanced text and the large unenhanced text when compared to the small unenhanced text. Subjects showed an average 7.1% increase in reading rate with enhancement and a 3.9% decrease with larger letters. Neither of these changes differed significantly from zero. As with our near threshold group in Experiment 1, we had large standard deviations for all three conditions. Therefore, the percent change from the SU text also varied widely. For the SE condition, the values ranged from -50.0% to 42.9% (a negative value indicating that the subject read slower with enhancement). For the LU condition percent change ranged from -15.8% to 150%.

These results, although preliminary, lead us to believe that it was not the increase in size alone that contributed to the increased reading rate for our near acuity threshold group in Experiment 1. If that had been the case, we should have found an increase in reading rate for the LU condition and equal or about equal reading rates for the SE and SU conditions.

General Discussion

Both Experiments 1 and 2 showed a significant increase in reading rate for scrolled text with contrast enhancement. For Experiment 1, this improvement was primarily found for those subjects reading near or below the five times acuity threshold Legge (1991) reported necessary for maximum reading speed. We hypothesized that this increase might have been due to the increased size of the enhanced characters. Experiment 2, as yet incomplete, tends to refute this hypothesis. We continue to find an improvement in reading rate for enhanced text even when compared with unenhanced text of the same size.

We were unable, however, in either Experiment, to match the 200 - 400% increases in reading rate Lawton (1992) reports. We were also unable to find a significant correlation between acuity and improvement with enhancement, as she reports. Two important differences in our methodologies may account for these differences.

First, our subjects were more visually impaired. We have not tested the possible effects of contrast enhancement for patients with acuity better than 20/100, as did Lawton (1989, 1992). Also, her conclusions must be tempered by the small number of subjects tested (3). In addition, she varied the reading distance for her subjects, presumably so that they would be reading near threshold. Therefore, her subjects would have been classified in our near acuity threshold group, for which we found the largest increase in reading rate. Even so, none of our subjects improved by 200% or more.

Second, and likely more important, was the repeated presentation of sentences in Lawton's (1989, 1992; Lawton et al., 1993) studies. This, and the fact that she did not report counterbalancing across conditions, leads us to believe that the large increases she found in reading rate were primarily due to a practice effect. If, as we suspect, the enhanced presentation always followed the unenhanced presentation, the repeated use of the same stimuli could easily have lead to her reported results. Our subjects saw each sentence only once, and the order of presentation for enhanced and unenhanced text was counterbalanced.

Acknowledgments

Supported in part by grant #EY05957 from the National Institutes of Health, by the Ford Motor Company Fund, and by DigiVision. In addition, the first author was supported by National Institutes of Mental Health grant #T32 NH19729 awarded to the Northeastern University Department of Psychology.

References

Lawton, T. B. (1989). Improved Reading Performance Using Individualized Compensation Filters for Observers With Losses in Central Vision, *Ophthalmology* **96**, 115-126.

Lawton, T. B. (1992). Image Enhancement Filters Significantly Improve Reading Performance for Low Vision Observers, *Ophthalmology and Physiological Optics* **12**, 193-200.

Lawton, T. B., Sebag, J., Frambach, D. A., & Sadun, A. A. (1993). Image Enhancement of Continuous Moving Text Improves Reading Performance of Age-Related Macular Degeneration Observers, *Investigative Ophthalmology and Visual Science (Suppl.)* **34**, 788.

Legge, G. E. (1991). Glenn A. Fry Award Lecture 1990: Three Perspectives on Low Vision Reading, *Optometry and Vision Science* **68**, 763-769.

Legge, G. E., Pelli, D. C., Rubin, G. S., & Schleske, M. M. (1985). Psychophysics of Reading II. Low Vision, *Vision Research* **25**, 239-253.

Peli, E. & Peli, T. (1984). Image Enhancement for the Visually Impaired, *Optical Engineering* **23**, 47-51.

Peli, E., Fine, E. M., & Pisano, K. (1993). Video enhancement of text and movies for the visually impaired. Paper presented at The International Conference on Low Vision, Groningen, The Netherlands.

Peli, T. & Lim, J. S. (1984). Adaptive Filtering for Image Enhancement, *Optical Engineering* **21**, 108-112.