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The Effect of Zoom Magnification and Large Display on Video Comprehension in Individuals With Central Vision Loss

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Received: April 22, 2020
Accepted: February 19, 2021
Published: July 29, 2021

Keywords: magnification; center of interest; zoom; movies; central vision loss

Citation: Costela FM, Reeves SM, Woods RL. The effect of zoom magnification and large display on video comprehension in individuals with central vision loss. Transl Vis Sci Technol. 2021;10(8):30, https://doi.org/10.1167/tvst.10.8.30

Purpose: A larger display at the same viewing distance provides relative-size magnification for individuals with central vision loss (CVL). However, the resulting large visible area of the display is expected to result in more head rotation, which may cause discomfort. We created a zoom magnification technique that placed the center of interest (COI) in the center of the display to reduce the need for head rotation.

Methods: In a 2 × 2 within-subject study design, 23 participants with CVL viewed video clips from 1.5 m (4.9 feet) shown with or without zoom magnification, and with a large (208 cm/82″ diagonal, 69°) or a typical (84 cm/33″, 31°) screen. Head position was tracked and a custom questionnaire was used to measure discomfort.

Results: Video comprehension was better with the large screen ($P < 0.001$) and slightly worse with zoom magnification ($P = 0.03$). Oddly, head movements did not vary with screen size ($P = 0.63$), yet were greater with zoom magnification ($P = 0.001$). This finding was unexpected, because the COI remains in the center with zoom magnification, but moves widely with a large screen and no magnification.

Conclusions: This initial attempt to implement the zoom magnification method had flaws that may have decreased its effectiveness. In the future, we propose alternative implementations for zoom magnification, such as variable magnification.

Translational Relevance: We present the first explicit demonstration that relative-size magnification improves the video comprehension of people with CVL when viewing video.

Introduction

Currently, there are an estimated 6.4 million people in the United States with low vision,[1] most of whom have central vision loss (CVL), and these numbers are expected to increase substantially as the population ages.[2] Individuals with CVL report watching television and movies at least as often as people with full sight,[3] but describe difficulty in recognizing faces, following movie plots, and understanding video content.[4] To assist people with CVL watch television, they may use Fresnel lenses attached to the surface of the display, optical devices (e.g., head-mounted telescopes), head-mounted electro-optical devices (e.g., eSight, Toronto, ON), relative-size magnification (e.g., a large display at same viewing distance), or relative-distance magnification (e.g., sitting close to the display without changing display size). However, vision aids are not used by many people to view TV,[3,5] while relative-distance magnification is commonly used,[3] and large displays are less common among older people with CVL.[3]

Relative-size magnification can be obtained by using a larger display while maintaining the same moderate viewing distance. Although this strategy has been recommended for people with CVL,[6] to our knowledge, there have been no studies that have shown a direct benefit from relative-size magnification for individuals with CVL in watching TV. Relative-size magnification is more commonly adopted by younger than older people with CVL.[3] Conversely, relative-distance magnification, obtained by decreasing the viewing distance, is commonly used by people with CVL.[3] A short viewing distance can be difficult to achieve or maintain, because it may interfere with the experience of others in the household, such as a chair in an awkward or inconvenient location obstructing the view of others, and may be impossible in some settings, such as viewing in bed. Although a large display can provide relative-size magnification when the viewing distance is maintained, alternatively, a large display can allow longer viewing distances for the same viewing angle, which might be beneficial while watching television in a room used by other people.

Many individuals with CVL have expressed interest in image enhancement technology for television viewing and computer use.[3] Among individuals with vision impairments, contrast enhancement was shown to improve perceived video quality.[7–12] However, the benefits found with contrast enhancement have been modest, and no contrast enhancement technique is available in a commercial device for TV and video enhancement for people with CVL. Similarly, only modest[13] or no[14] benefits have been shown for edge enhancement of video, and no devices for edge enhancement of TV and video enhancement are available. Contrast and edge enhancement have been implemented in a variety of head-mounted devices designed for use by people with reduced vision, but we are not aware of any studies that have reported their use for viewing TV or video.

An alternative is to electronically magnify the video. However, a side effect of magnification is that the visible area is reduce by the inverse square of the magnification. So, with 2× magnification, only 25% of the original view can be shown; that reduce to 11% with 3× magnification. The reduced visible area causes a loss of context as information may be lost to the magnification (comparable with the magnification scotoma of an optical magnifier). An approach that might mitigate that limitation involves zoom magnification.[15] Instead of magnifying simply, such that the center of the original image is the center of the magnified view, magnifying around the object or center of interest (COI) mitigates the loss of information from a reduced visible area.[15] Zoom magnification, around the COI, may prove beneficial to individuals with CVL, as important objects of interest are automatically magnified and are in the image center and thus easier to find. Being in the center should reduce the need for searching eye movements and failures to identify a new object of interest that by chance was in the scotoma of the viewer with CVL.

Objective assessment of a benefit from video enhancement has been a challenge, with no solution[16] until recently.[17] Our approach obtains a free recall response by asking participants to describe (in natural language) short video clips, after which responses are scored objectively to provide a measure of video comprehension that we called sensory information acquisition (IA).[17] Previously, we have used this IA method to demonstrate a decline in IA scores with increasing defocus blur,[17] and to be decreased among people with CVL,[4] hemianopia,[18] and Alzheimer's disease.[19]

In the present study, we examined the effects of relative-size magnification and zoom magnification on video comprehension, head motion, and discomfort of the head, neck, and eyes. For people with CVL, we hypothesized that (1) relative-size magnification would improve video comprehension and cause more head rotation and discomfort, and (2) zoom magnification would improve video comprehension, require fewer head movements, and cause less discomfort.

Methods

Participants

Participants were recruited from the community in and around Boston, Massachusetts. Participants were eligible for the study if they scored above 20 on the Montreal Cognitive Assessment[20,21] and had a corrected binocular VA between 0.35 logMAR (20/45) and 2.0 logMAR (20/2000). The binocular visual acuity (VA) of all subjects was assessed using a computerized single-letter VA test; contrast sensitivity was assessed using the Mars Letter Contrast Sensitivity Test,[22] and binocular visual fields were assessed using a custom computerized visual-field mapping program.

Of the 23 individuals with CVL who participated in the study (median age 58.3 years; range 18–74 years), 12 (55%) were male and 14 (61%) had a bachelor's degree or higher. The mean VA of all subjects was 1.00 (range, 0.37–1.88) logMAR (mean 20/200, range 20/47 to 20/1500). Participant vision and demographic characteristics, including vision impairment diagnosis as reported by the subject, are shown in the Table.

Experimental Design

The study was a 2 × 2 repeated measures, within-subject design. Each participant watched up to 20 short (30-s) video clips in up to four viewing conditions, with five clips per viewing condition. There were two screen sizes and two magnification levels that totaled four conditions. The order of the conditions and video clips were assigned randomly per participant and shown in four viewing condition blocks. The

Table. Vision Characteristics of the Participants With CVL

Participant	Gender	Age	Binocular VA (logMAR)	Binocular CS (log)	Diagnosis
1	Male	52.9	1.10	0.48	Stargardt’s disease
2	Male	66.6	1.10	0.36	JMD
3	Male	60.3	1.50	0.68	Glaucoma (OD), retinal detachment (OS)
4	Male	48.2	1.42	0.16	Optic atrophy
5	Female	61.5	1.02	1.2	Optic atrophy
6	Female	66.6	0.60	1.48	Doyne honeycomb retinal dystrophy
7	Male	45.9	1.80	N/A	Leber’s optic neuropathy
8	Male	60.4	0.88	1	Stargardt’s disease
9	Female	18.1	1.44	0.52	Stargardt’s disease
10	Female	75.0	0.72	0.72	Wet AMD
11	Male	74.4	1.30	0.36	Stargardt’s Disease
12	Male	62.2	0.92	0.96	Myopic degeneration
13	Male	66.5	0.57	1	Myopic degeneration
14	Male	53.9	0.90	1.12	Optic nerve atrophy
15	Female	33.0	1.24	1.04	Stargardt’s disease
16	Female	66.5	0.90	0.92	JMD
17	Male	56.1	0.86	0.8	Macular degeneration
18	Male	38.0	1.40	N/A	Optic nerve atrophy
19	Male	67.3	1.06	N/A	Stargardt’s disease
20	Female	51.0	0.82	1.4	Congenital cataracts, nystagmus
21	Female	54.4	0.38	0.96	Stargardt’s disease
22	Female	58.7	0.60	1.4	Macular degeneration
23	Female	53.5	0.80	1.28	Stargardt’s disease

AMD, age-related macular degeneration; CS, contrast sensitivity; JMD, juvenile macular degeneration; logMAR, logarithm of the minimum angle of resolution; N/A, not available; OD, right eye; OS, left eye; VA, visual acuity.

two screen size conditions were (1) a “small” screen size with 84 cm (33 in) diagonal (16:9 aspect ratio), that was 31° visual angle when viewed from 1.5 m (59 in) (Figs. 1A, 1B), and (2) a “large” screen size with 208 cm (82 in) diagonal (16:9 aspect ratio), that subtended 69° visual angle (Figs. 1C, 1D). The difference in screen sizes produced a magnification of 2.5 times. The two magnification conditions were (1) the original clip (100% of the original scene with no magnification) (Figs. 1A, 1C) and (2) zoom magnification around the democratic COI (25% of the original scene) (Figs. 1B, 1D) (see the COI Determination and Magnification Method section).

Participants sat 1.5 m from the display throughout the experiment. Head position was not constrained. Before watching the set of 20 video clips, participants watched a video for 30 minutes with the largest screen size while wearing a gaze- and head-tracking device (see the Head Tracking section) to become accustomed to the setup and also to increase the likelihood of reporting discomfort with increasing time on task.

COI Determination and Magnification Method

Zoom magnification uses the COI to determine the center of the magnification. The rationale is based on the observation that most people with normal vision look in about the same place most of the time when watching directed video content (e.g., “Hollywood” movies and television shows).[23,24] From that, we infer that the gaze is directed to objects of interest, as intended by the director of the video content. We call this common gaze location the democratic COI. Previously, we collected gaze data from 60 subjects with normal vision on a database of 200 video clips, such that each of the 30-second video clips was watched by at least 12 subjects.[25] We removed saccades from

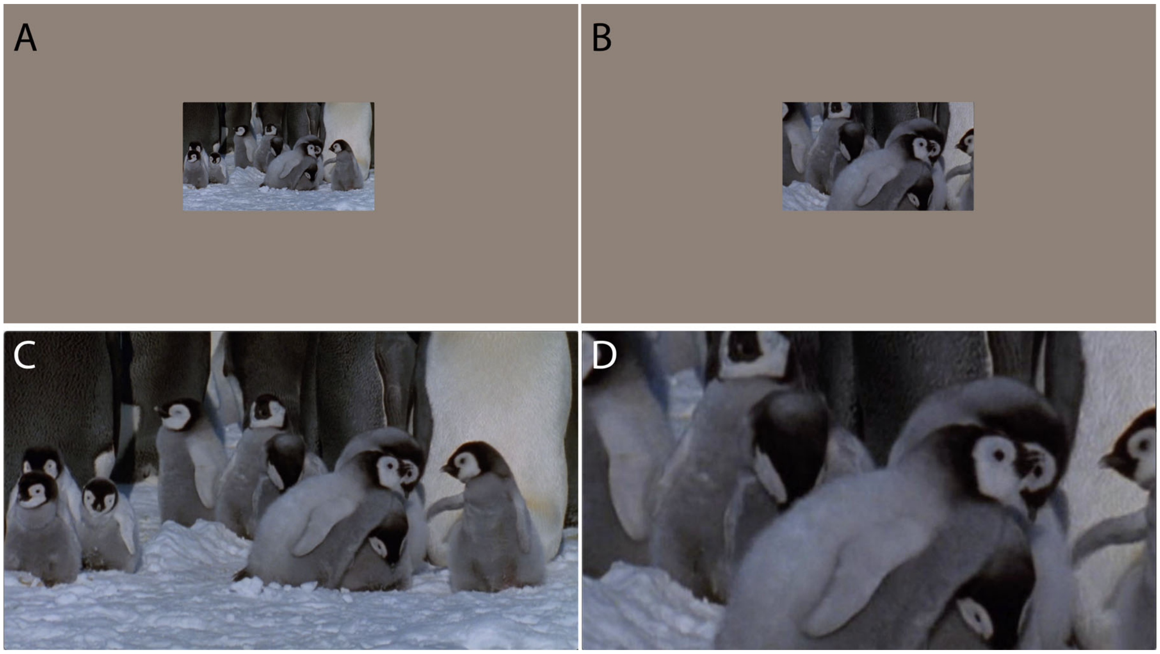

Figure 1. Illustration of the experiment using a video frame from "March of the Penguins" (2005). Viewing conditions: (**A**) "Small" screen size, 33″ diagonal, with original clip; (**B**) "Small" screen size, 33″ diagonal, with zoom magnification (2× magnification); (**C**) "Large" screen size, 82″ diagonal, with original clip; and (**D**) "Large" screen size, 82″ diagonal, with zoom magnification (2× magnification).

the data and computed a kernel density estimate of the fixation points for each frame. For each frame, we integrated the area under the region of the density estimate for all different positions of a 2× magnification box (contains 25% of original) across the frame interpolating with a symmetrical Gaussian function to determine the optimal position for the visible area that contained 25% of the original scene. This visible area was the region of magnification. Once the visible area coordinates were obtained, we applied a deadband filter of 60 pixels followed by a smooth quadratic filter with a span window of 10% of the sample size to avoid jitter. Then, all frames were composited together to create the new zoom magnification video clip.

IA Task and Video Clips

IA is an objective measure of the ability to perceive and understand a video clip, using descriptions made by the observer. Participants viewed up to twenty 30-second video clips in a randomized order wearing their habitual optical correction. After each clip, the subject responded to a simple, instruction without time constraints. An experimenter gave the initial instructions and was in the room during data collection. The MATLAB program automatically displayed the prompts after viewing each clip, asking the participant to provide verbal responses to the open-ended queries: "Describe this movie clip in a few sentences, as if to someone who has not seen it," and then, "List several additional visual details that you might not mention in describing the clip to someone who has not seen it." The spoken responses to each prompt were recorded using a headset microphone and later transcribed. From the 23 subjects, we obtained 436 descriptions of video clips.

The set of 20 video clips, each of 30 s duration, used in the study was obtained from a freely available online dataset of 200 video clips.[25] The clips included a range of types of depicted activities and genres, including drama (e.g., *Dreamgirls*), comedy (e.g., *Juno*), documentary (e.g., *Food, Inc.*), and animation (e.g., *Coraline*). The clips included conversations, action sequences, indoor and outdoor scenes, and wordless scenes where the relevant content was primarily facial expressions or body language. The average number of cuts in that database was 9 per minute as compared to approximately 12 per minute in contemporary films.[26] The clips were displayed by a MATLAB program using the Psychophysics Toolbox[27] and Video Toolbox.[28]

IA Scoring

The verbal responses were transcribed using Amazon Mechanical Turk,[29] an internet crowdsourcing marketplace that allows the use of human intelligence to perform tasks that computers cannot. As described elsewhere,[17] the transcriptions were objectively scored for their relevant content using an automated "wisdom of the crowd"[30] approach. Each new response was compared to each of the responses to the same video clip in a control reference database of responses from 159 participants with normal vision that included responses from 99 crowd-sourced participants and 60 laboratory-sourced participants.[17,31] The number of words (after removing stop words such as "a," "the," and "at," and fillers such as "um" and "eh") shared by each pair of responses, disregarding repeated instances of the word in either response, produced a shared word count for each pair of responses. The IA score for each video clip for each study participant was the average of the shared word counts from the paired comparisons with each of the responses from the control database for that clip.

Head Tracking

Participants wore an EyeLink II (SR Research, Ottawa, Ontario, Canada) helmet throughout the experiment. We were only able to calibrate the EyeLink II system with 4 of the 23 subjects with CVL, so we present no data for gaze. The difficulty with calibration seemed to have been caused by the use of a preferred retinal locus for fixation by many of the subjects, which induced some ocular rotation, and which would cause a section of the nine-point calibration grid (usually a corner) to fail in the calibration process (typically the system would be unable to hold the pupil). Infrared reflectors were attached to the helmet, which, in conjunction with an infrared camera, allowed us to track head movements. A separate computer was used to calibrate the head position and collect head tracking data during the whole session. We synchronized clocks in all data collection computers to align the head tracking samples that corresponded with each trial and obtained an average of approximately 120 samples per second (approximately 3,600 samples per clip). From 15 subjects, we obtained head rotation data during viewing of 299 video clips. For each sample, we extracted the angle between the horizontal component of the head motion and a baseline calculated as the average horizontal position of the head during that screen size (31° or 69° diagonal). Finally, we calculated the average of the absolute value of all the angles during that trial to obtain a metric that reported the amount of head motion during each trial.

Discomfort Questionnaire

At the end of each block, participants were asked to rate their level of discomfort on a Likert scale that ranged from 0 (not at all) to 5 (extremely) in response to four questions:

(1) Do you feel fatigued or tired now?
(2) Do you have discomfort in your neck or shoulders now?
(3) Are your eyes tired, aching, itchy, or scratchy now?
(4) Are you having difficulty following the story now?

The questionnaire was embedded in the MATLAB script so that it appeared automatically after each block. Verbal responses from the subject were entered by the experimenter. From 23 subjects, we obtained 85 completed discomfort questionnaires.

Data Processing and Analyses

Statistical analyses were conducted using Stata/IC 14 for Macintosh (Stata Corp, College Station, TX). We examined the impact of viewing condition, VA, and order on IA scores with a linear mixed model with age, gender, and education as covariates, and participant and video clip as fully-crossed random effects. We examined the effects of viewing condition on head motion using a linear mixed model that included VA and order as fixed factors, and age, gender, and education as covariates, and participant and video clip as fully crossed random effects. For that analysis, we used the logarithm of head rotation, which approximately normalized (Shapiro-Wilks test; $z = 2.14$; $P = 0.02$) the otherwise skewed distribution. We examined the effects of viewing condition on responses to the discomfort questionnaire in a series of mixed effects, ordered logistic regressions that included head motion and order as fixed factors, and age, gender, and education as covariates, and participant as a random effect. Viewing condition was included in the models described elsewhere in this article as the full 2 × 2 factorial, with screen size, zoom magnification, and their interaction.

Linear mixed models are robust to certain missing data, and the random effects account for repeated measures by including terms for individual differences between subjects (e.g., some people are more loquacious or more observant) and between video clips (e.g., some clips are harder to describe or have less material to report). Because we have previously found

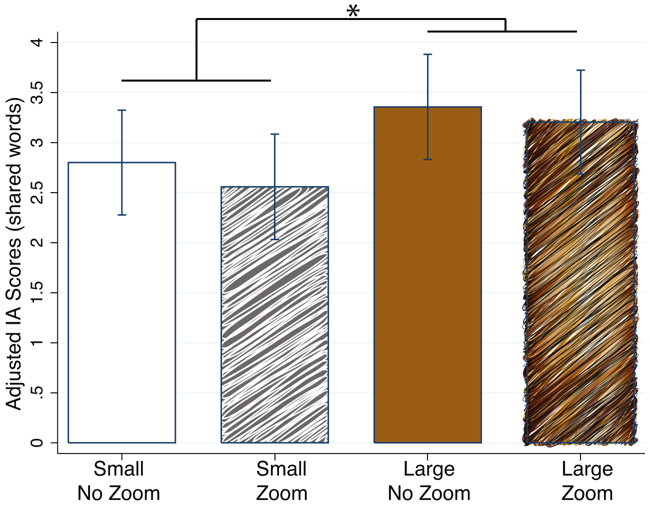

Figure 2. Fitted IA scores across viewing conditions. IA scores were higher with the large screen and tended to be lower with zoom magnification. Error bars represent 95% confidence intervals. Asterisk represents significance between groups ($P < 0.001$).

that IA scores can vary with age, education, and gender,[4,17–19] we included these demographic factors as covariates. To determine whether subjects were aware of their ability (and, conversely, their limitations), we fit a mixed-effects ordered logistic model to the data from question 4 that had IA score, VA, and order as fixed factors, and participant as a random effect. As a compromise between the risks of type I (multiple comparisons problem) and type II (small sample size) errors, we accepted a P value of 0.01 or less as statistically significant, and report terms with $0.10 \geq P > 0.01$ as trends.

Results

IA Scores Were Associated With Screen Size and VA

Both a large display (relative-size magnification) and zoom magnification were expected to provide better video comprehension (higher IA scores) as compared to a smaller screen size or no zoom magnification (original). As shown in Figure 2, IA scores were significantly higher in the large screen condition ($b = 0.59$ shared words; $z = 3.70$; $P < 0.001$). Unexpectedly, there was a trend for zoom magnification to lead to lower IA scores ($b = -0.28$ shared words; $z = 1.76$; $P = 0.08$). The interaction between zoom magnification and the screen size was not significant ($z = 0.42$; $P = 0.68$). As shown in Figure 3, IA scores decreased with worsening VA ($z = 2.91$; $P = 0.004$) as expected.[4] In this sample, IA scores were not related to trial order ($P = 0.30$), gender ($P = 0.32$), age ($P = 0.\ 43$), or education level ($P = 0.90$).

Zoom Magnification Increased Head Motion

We expected that head rotation would be greater with the larger than with the smaller display. Given that zoom magnification places the COI in the center of the display, we hypothesized that zoom magnification might decrease the amount of head motion. Surprisingly, head rotation did not differ between the two display sizes ($z = 0.51$; $P = 0.61$), while head rotation was greater with zoom magnification ($z = 3.37$; $P = 0.001$). The interaction between zoom magnification and the screen size was not significant ($z = 1.10$; $P = 0.27$). There was a trend for head rotation to decrease over the sessions ($z = 2.19$; $P = 0.03$), suggesting that the study caused some fatigue.

Display Size, Zoom Magnification, and Head Rotation Were Not Related to Discomfort

We hypothesized that increased head movements would be associated with discomfort, as measured with the three questions: (1) overall tiredness, (2) neck and shoulder fatigue, and (3) eye fatigue. Across the three questions, we found that display size ($z \leq 1.29$; $P \geq 0.20$), zoom magnification ($z \leq 0.94$; $P \geq 0.35$), and head rotation ($z \leq 0.67$; $P \geq 0.50$) did not have an effect on discomfort. Across all three questions, discomfort increased as the study progressed ($z \geq 2.50$; $P \leq 0.01$). This result indicates that the three questions were working as anticipated.

Using question 4, we asked whether the subjects were aware of their ability to comprehend and describe the video clips. Perceived ability to follow the story (Q4) was not related to measured ability to follow the story, the IA score ($z = 1.27$; $P \geq 0.20$), or VA ($z = 0.20$, $P = 0.84$). Interestingly, 74 of the 85 responses to the question were “not at all,” which is inconsistent with most people with CVL having a reduced IA score compared to people with normal vision.[4] However, it is consistent with an unpublished analysis in which we compared IA scores of subjects with CVL[4] with their reports of perceived difficulty watching TV (survey item[3]); IA scores were unrelated to perceived difficulty (Spearman, $n = 16$; rho $= -0.39$; $P = 0.14$).

Discussion

Relative-distance magnification has long been advocated as effective for viewing television with

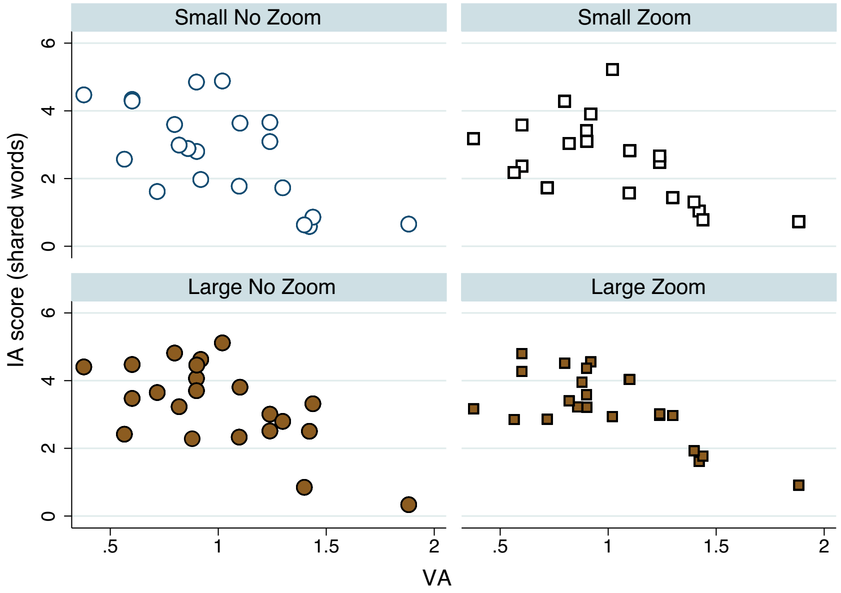

Figure 3. Average IA score decreased with worsening VA. Each symbol represents a participant. Color encodes screen size; shape encodes the use of zoom magnification.

CVL (e.g.,[6]) and is commonly used by people with CVL.[3] Relative-size magnification is achieved by using a larger format (e.g., larger page or larger font when reading[6]). Changes in technology in the last few decades have made large television screens widely available, which allows the use of relative-size magnification for watching television. However, in a survey, Woods and Satgunam[3] found that although younger people with CVL were using large televisions, older people with CVL tended to be using typical sizes (similar to participants with normal vision). Perhaps vision rehabilitation providers should be recommending that younger relatives purchase and install large televisions for their elderly relatives.

Here, to our knowledge, we provide the first study of the benefit of using a large display, in combination with a "short" viewing distance (the median viewing distance of people with CVL reported in a survey[3] was 1.5 m (5 ft), the viewing distance in our study) for viewing TV or video. When considering visual angles, the effect would have been the same if the viewing distance had been decreased and a smaller display used (in our study, the viewing distance was constrained by the head tracking system). Our large display subtended 69° diagonal visual angle (208 cm from 150 cm/82" from 59"). Televisions of that size (208 cm / 82") are available, but not common and currently are expensive. A 69° visual angle could be obtained with a 140 cm (55") display viewed at 1 m (39") or a 104 cm (41") display viewed at 75 cm (30"). Thus, comparable viewing angles can be achieved with smaller, moderately priced displays.

The concept of zoom magnification is that the COI is always at the center of the display, which should decrease the need to search for objects of interest (which can be hidden by a central scotoma), and provide some resolution assistance through the magnification. The COI is expected to be the location of the most important information, which is why people with normal vision look there.[23,24] As compared to simple magnification (around the original image center), zoom magnification decreased the information loss caused by the restricted visible area.[15] In an analysis that compared equivalent visible areas, a visible area restriction to 25% of original, as here (2× magnification), produced a reduction in IA score of about 0.6 shared words with simple magnification (around the original image center). In contrast, zoom magnification (around the COI) produced a decrease of about 0.4 shared words. So, zoom magnification ameliorated the effects of a restricted visible area, providing a benefit over simple magnification, but IA scores were still decreased compared with the original (no magnification). That study was in a sample of participants with normal vision, for whom magnification provided no benefit. In the present study, we found a reduction in IA score of about 0.3 shared words with the zoom magnification as compared with original, which is about the same decrement as found in the earlier study of participants with normal vision. Surprisingly, it implies that the increased resolution provided by the effective magnification was not beneficial to our subjects with CVL, because the lower IA score seems to reflect the loss of context alone.

Magnification of this magnitude (about 2×) usually produces helpful increases in reading speed in people with CVL.[32] For reading, visible area restriction reduces reading speeds when reading speed is "faster," but may not be the main limiting factor when reading speeds are "slower."[33] That video comprehension was better with the large screen than the small screen shows that relative-size magnification was helpful to our participants with CVL when there was no decrease in the visible area. This result leaves the question of why the magnification provided by zoom magnification was not helpful. Feedback from our participants about their experience of zoom magnification could be categorized into three main themes: (1) it was fairly "natural" and not readily distinguished from normal camera zooms and pans found in the original video, (2) on occasion, the object of interest was not visible or vacillated between two objects of interest so that neither was easily viewed, and (3) sometimes that object of interest was not well-framed, with the most annoying being when the magnification caused the object to be cropped (e.g., unable to see all of the actor's head or all of a vehicle). The last two comments suggest that we did not provide an optimal implementation of zoom magnification.

In the next phase of zoom magnification development, we aim to improve the visible-area-center algorithm to decrease the likelihood of incidents wherein the object of interest is not shown. On review of many video clips with zoom magnification, it seemed that there were two main causes of these incidents: (1) when there were two objects of interest, the most common example of this being when there were two characters in a conversation and both heads visible, so that viewers would look back and forth between the characters, not necessarily in concert with whom was speaking, because viewers might look to the listener to see a response to what had been said, and (2) in the original video, after a shot cut (e.g., viewpoint or scene change), the new COI was in a different location on the screen, and there was a transition of gaze from the before COI to the after COI that took up to about 0.5 seconds (includes time to identify new saccade target). The current algorithm used in the study presented here smoothly moved the visible area center to the new COI, and potentially had inadvertent effects that the object of interest was not within the visible area for much of that period across the shot cut.

To reduce the second problem, we identified cuts using a version of shot transition detection that we used recently.[34] Once identified, instead of drifting the COI, we immediately moved the visible area center to the new COI at the time of the shot cut. These changes to the visible area–center algorithm might reduce instances of "missing" the object of interest across shot cuts.

To reduce the first problem, we propose new visible area–center algorithm rules that do not allow shifts of the COI that fail to reach a new COI before returning to the first COI when there are two competing COIs (e.g., two characters or objects interacting). Such rules will need to be written carefully and include information about the COI over a much longer time frame than we used in the smoothing, and so is likely to require adjustments to the spatial smoothing. Allowing the magnification to be variable may also decrease the vacillation problem. Variable magnification would reduce magnification when the spread of the gaze distributions was wide, as is found in two person conversation scenes as a bimodal distribution or in crowded scenes (see Fig. 4, left column).

The problem of cropped subjects of interest could be interpreted as the director having already zoomed in, so our added zoom magnification lead to "over" magnification, causing object cropping. To reduce this problem, we propose using face and object detection in the future (e.g., histogram of oriented gradients,[35] TinyFaces,[36] convolutional neural networks[37]) to identify the outline or extent of objects of interest that is the COI (object segmentation[38]), and then to adjust the magnification to ensure that the face or object is not cropped. An alternative method to decrease object cropping might be to use variable magnification.

As a preliminary test of variable zoom magnification, we conducted a pilot study. The spread of the gaze distribution was used to control the magnification. An illustration of this first implementation of the approach is shown in Figure 4. The visible area–center algorithm was the same as in the main study. Five participants with CVL (who did not participate in the main study) were shown video clips that were original (no magnification) or two versions of zoom magnification: (1) current fixed magnification (as used in our study) and (2) new variable magnification (using the gaze distributions). Clips were shown side by side, synchronously, and subjects indicated their preference (paired comparisons[39,40]), and provided feedback in debriefings. Each display was 104 cm diagonal, and the subject viewed from 1 m without head restraint. Each subject saw all 3 potential pairings with 5 different video clips each for a total of 15 pairings. Compared with original, fixed magnification was not preferred (mixed effects logistic regression: $z = 1.82$; $P = 0.07$), and variable magnification was strongly preferred

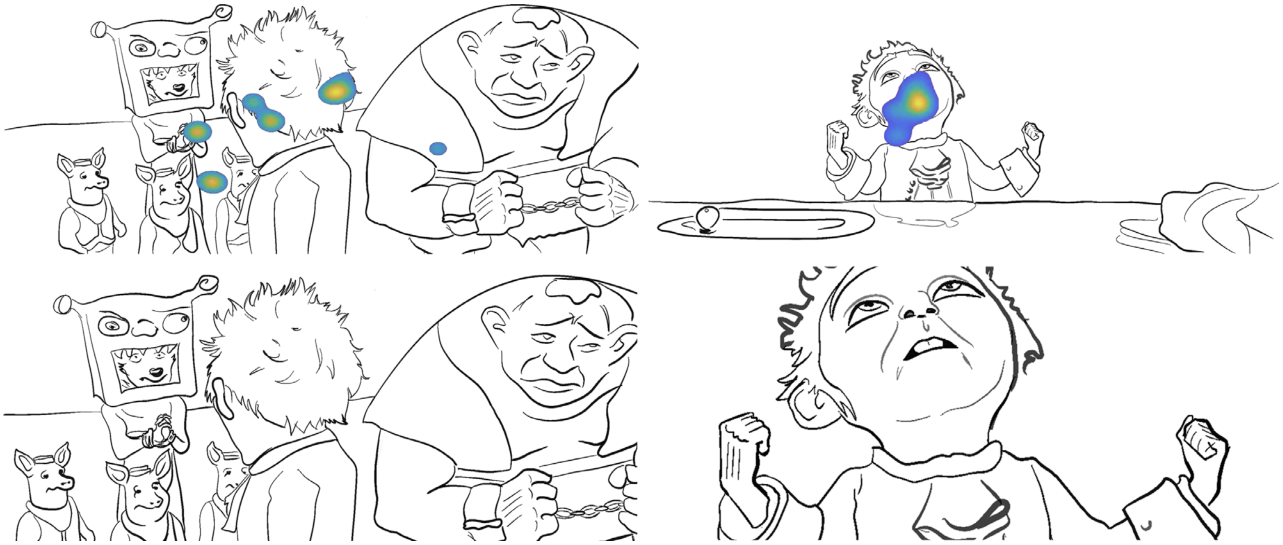

Figure 4. Top row: Illustrations of video frames in "Shrek Forever After" (2010) that show the gaze distributions (density kernel) when viewing the video clip. The gaze distribution was wide on the left and narrow on the right. Bottom row: Variable zoom magnification was lower with a wide gaze distribution (left) and higher with the narrow gaze distribution (right).

($z = 3.27$; $P = 0.001$). Participants reported that variations in magnification over short periods that could appear as fluctuations were sometimes distracting, indicating that the temporal smoothing algorithm needs improvement. Overall, this pilot study provided strong evidence that variable-zoom magnification is likely to be a substantial improvement and worthy of further investigation. This is evidence that the concept of zoom magnification was probably not the cause of the failure to find a benefit; instead, it was a failure of the implementation that we used.

In the present study, when using a screen with a large viewing angle, we expected that eye movements would be insufficient and uncomfortable and that head rotation would be used to supplement eye movements for viewing objects of interest. That was not the case. Instead, both head rotations and discomfort (head and shoulders, and general tiredness) were the same for the two display sizes. We do not know why head rotations were not larger. We did find a decrease in head rotation and increases in neck and shoulder discomfort across the session, indicating that we had the ability to find effects.

Because zoom magnification keeps the COI in the center of the display most of the time, we had expected that head rotations would be less than with the original clip (no magnification), and thus discomfort would be less. Contrary to our expectation, head rotations were greater with zoom magnification, although there was no difference in neck and shoulder discomfort or general tiredness. It is possible that participants had to make larger gaze changes because the objects were magnified, and at least some of that was achieved using head changes. We could not investigate that hypothesis, as we were unable to track the eye movements of 19 of 23 subjects using an EyeLink II (a head-mounted, infra-red, video-based) system. Possibly, subjects felt that they had missed visual information (when the visible area was decreased with zoom magnification), and increased their head movements to search for that "missing" contextual information. However, in a study in which subjects with CVL watched original clips, we found they seemed to follow the same video scan path as subjects with normal vision.[41]

In summary, this first implementation of zoom magnification failed to find a benefit from this novel approach. We were able to identify problems with our implementation and propose a number of modifications that are likely to increase the likelihood of benefit from an improved implementation. Given the numbers of people with CVL, and that they watch television, but have difficulty watching television, developing vision rehabilitation aids for watching television is worthy of further work. In addition, we were able to confirm clinical experience with the first explicit demonstration that relative-size magnification is an effective intervention for viewing television for people with CVL. Perhaps surprisingly, we found that even with a large viewing angle (69°) the discomfort and tiredness experienced by extended viewing of television was not exacerbated.

Acknowledgments

The authors thank Jih-Ping Chern for developing the head-tracking software, John F. Ackermann for developing the method to determine the center of magnification, and Gwyneth L. Woods for the line drawings used in Figure 4.

Supported by National Eye Institute awards R01EY019100 and P30EY003790.

Eli Peli conceived of the general concept of zoom magnification.

Disclosure: **F.M. Costela**, None; **S.M. Reeves**, None; **R.L. Woods**, None

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