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Perceived contrast of electronically magnified video

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ABSTRACT

It has been observed that electronic magnification of imagery results in a decrease in the apparent contrast of the magnified image relative to the original. The decrease in perceived contrast might be due to a combination of image blur and of sub-sampling the larger range of contrasts in the original image. In a series of experiments, we measured the effect on apparent contrast of magnification in two contexts: either the entire image was enlarged to fill a larger display area, or a portion of an image was enlarged to fill the same display area, both as a function of magnification power and of viewing distance (visibility of blur induced by magnification). We found a significant difference in the apparent contrast of magnified versus unmagnified video sequences. The effect on apparent contrast was found to increase with increasing magnification, and to decrease with increasing viewing distance (or with decreasing angular size). Across observers and conditions the reduction in perceived contrast was reliably in the range of 0.05 to 0.2 log units (89% to 63% of nominal contrast). These effects are generally consistent with expectations based on both the contrast statistics of natural images and the contrast sensitivity of the human visual system. It can be demonstrated that 1) local areas within larger images or videos will usually have lower physical contrast than the whole; and 2) visibility of 'missing content' (e.g. blur) in an image is interpreted as a decrease in contrast, and this visibility declines with viewing distance.

Keywords: Perceived contrast, electronic magnification, blur, video, image scaling

1. INTRODUCTION

Magnification of imagery results in a decrease in angular resolution, and so the resulting image is often visibly blurred. In cases where electronic magnification is useful or necessary[1,2], the perceptual impact of such blur is not well understood. While developing visual rehabilitation aids for people with reduced vision that use electronic magnification we noticed an apparent attenuation of image contrast. Here, we measure this effect using video stimuli and localize its cause both to physical variations in contrast within complex images, and to a perceptual effect linked to the visible pixelation of the magnified videos.

Two general hypotheses are available to explain the difference in perceived contrast between normally displayed and magnified video. First, any subregion of an image containing varied content is likely to have a smaller range of contrasts than the original, so observed differences in contrast may have an entirely physical basis. Second, contrast can be conflated by observers with sharpness[3,4,5], so it may be that when blur or pixelation is recognized in an image, it provokes a sensation of contrast loss.

We evaluated the effect of electronic magnification on perceived contrast by having subjects equate the apparent contrast of a normally-displayed video clip with a magnified version of the same video clip. To test the first hypothesis, that differences between local and global image contrast are responsible for the perceived contrast effect, we carried out the experiment with and without cropped versions of the original video. We found that the apparent difference in contrast was strongly affected by the presence of content outside the magnified area, supporting the physical contrast difference hypothesis, but that there was an additional, purely perceptual effect not explained by the presence of the cropped material. To test the second hypothesis that this effect was due to the perceived blur of the magnified videos, we repeated the experiment at multiple viewing distances, including at a distance great enough that the pixelation or blur of the magnified video should have become invisible[6]. Under this condition, we found that the apparent contrast effect was nearly abolished when cropped original videos were used, but it remained when full-sized originals were used, lending further support to the notion that while the perceived contrast is related to blur it is also affected by the consistent difference in local versus global contrast.

2. METHODS

2.1 Stimuli

Stimuli were 100 3-second video clips drawn at random (excluding segments containing scene cuts) from two DVD movies and played continuously in a forward-backward loop until subject response. All videos were displayed in grayscale (no color). Videos could be displayed in one of three ways: 1) full-size original, where each frame was 360x360 pixels taken directly from the center of a DVD frame, 2) cropped original, where only the central portion to be magnified on a given trial was displayed (e.g. a 120x120 pixel video for 3x magnification), and 3) magnified, where the central portion of the original video was expanded through bilinear interpolation[7] to 360x360 pixels. Later, we will discuss video pixels, which are the pixels of the original video. For original videos, video pixels and (physical or monitor) pixels are the same size, but with magnification, video pixels increase in size. When magnified, due to the bilinear magnification, video pixels usually contain some range of luminances. Videos were centered 184 monitor pixels to the left and right of the center of the display.

2.2 Procedure

Subjects performed a discrimination task, choosing which of two side-by-side videos had the higher contrast. A 1-up 1-down staircase adjusted the contrast of the original video (the 'test') in.05 log unit steps from trial to trial, according to whether on the previous trial the test was chosen as having higher contrast (resulting in a decrease in test contrast) or whether the 'standard' was chosen (resulting in an increase in test contrast). This procedure adjusted the contrast of the original video to match the apparent contrast of the magnified video. Each separate staircase ran for 60 trials.

To allow test video contrast to be physically greater than the standard when necessary, standard video contrast was reduced in each experiment by -0.2 log units (to 63% of original). Test and standard contrast were set by the adjusting the entire video's RMS (root mean square) contrast as shown in Eq. 1, where V is the source video, V' is the adjusted contrast video, c is the contrast adjustment in log units with respect to the original contrast, and μ_V is the mean value of all pixels in the video:

$$V' = 10^c \left(V - \mu_V\right) + \mu_V \,. \tag{1}$$

Separate staircases were used within a block of trials for trials with test and standard on different sides of the display (i.e. each block of trials consisted of interleaved left-side and right-side staircases), for different standard contrast reductions, and for different magnification levels. At the end of each experiment, trials were binned by staircase and test contrast (left- and right-side staircases were combined) and fit with a logistic function estimating the proportion of trials at a given test contrast where the test video would be chosen as having higher contrast:

$$p\left(C'_{\text{test}} > C'_{\text{stand}}\right) = 1 - \frac{1}{1 - \exp\left(\dfrac{c_{\text{test}} - c_{\text{match}}}{\lambda}\right)} \,. \tag{2}$$

Here C' denotes perceived contrast of the test or standard videos, c_{test} the physical contrast of the test video, and c_{match} the contrast of a test video that yields a perceptual match between test and standard C' values. λ was set by the slope of the function, being proportional to the width of the transition between seeing the test as higher-contrast and seeing the standard as higher-contrast.

2.3 Subjects

Six subjects participated in Experiments 1 and 2; five of these subjects also participated in Experiment 3. Subjects were in the age range of 22 to 50y, all with normal or corrected-to-normal visual acuity and with no known visual impairments. Subjects viewed the display at 1, 3, or 5m depending on the experiment. Subjects were instructed to choose, on each trial by pressing the 'left' or 'right' arrow keys on a keyboard, indicating which video seemed to have the higher contrast. Two definitions for 'higher contrast' were given to each subject: 'larger range of grayscale values' (for the more experienced) and 'brighter whites/brights and darker blacks/darks' (for both experienced and naive subjects). Subjects were also instructed to choose not on the basis of single features within videos, but rather to try to estimate the *overall* contrast of the video (admittedly difficult and subjective, and we do not doubt that subjects varied in their ability to accomplish this), over both spatial extent and over time.

2.4 Equipment

The display used was a Sony Trinitron p1103 CRT, run at 800x600 (0.476 px/mm) resolution and 144Hz frame rate. The display luminance/voltage function was linearized by adjusting the gamma of the three color guns via the video software (nVidia GeForce 9400GT). Mean display luminance was 47cd/m^2. Experiments were carried out on a PC system running Matlab 7.5 with the Psychophysics Toolbox extensions[8,9].

3. EFFECTS OF MAGNIFICATION

3.1 Experiment 1: Varying Magnification Level with Full-sized and Cropped Originals

The effect of magnification on the difference in apparent contrast between original and magnified videos was tested at three magnification levels: 2x (180px magnified to 360px), 4x (90px magnified to 360px), and 6x (60px magnified to 360px). Those magnified videos were compared either with full-size (360px) unmagnified (original) videos or with the original video cropped to contain only the content displayed in the magnified video. For the cropped original condition, the two videos on each trial contained identical spatial content and thus identical luminance distributions, except that one had been magnified by bilinear interpolation. The cropped original videos were 180px, 90px or 60px in size for the 2x, 4x and 6x magnification levels, respectively. The full-size and cropped original conditions were conducted in separate blocks with half of the subjects performing the full-sized original condition first. All three magnification levels were assigned their own left- and right-side staircases and interleaved randomly in a block of trials. Having six interleaved staircases reduced the risk of a subject's 'tracking' the staircases. Subjects viewed the 360px videos at 1m, so the videos subtended 9.8° (of visual angle).

Results shown in Figure 1 plot the physical difference between perceptually-matched contrast levels (c_{original} - $c_{\text{magnified}}$) for the three magnification levels; negative values mean that original video matches underestimated magnified contrast (i.e. magnification *decreased* perceived contrast), positive values mean that original video matches overestimated magnified contrast (i.e. magnified *increased* perceived contrast). For all subjects, for each magnification level and both original conditions, the physical difference was negative – subjects always underestimated the contrast of the magnified videos. Furthermore, increasing the magnification level had the effect of increasing the apparent difference in contrast between original and magnified videos (ANOVA main effect of magnification, $F_{2,10} = 11.9$, $p = 0.002$). For the smallest magnification level used (2x) the median apparent difference in contrast was (across subjects) -0.07 log units and for the greatest magnification level (6x) the median difference was around -0.12 log units for the full-size originals (squares in Figure 1) and was -0.05 log units for the smallest (2x) magnification and -0.19 log units for the largest (6x) magnification with the cropped originals (diamonds in Figure 1). Overall, for the cropped-original condition the effect was slightly greater (main effect of condition, $F_{1,5} = 6.1$, $p = 0.06$) and the effect varied slightly more with magnification (magnification/condition interaction, $F_{2,10} = 3.02$, $p = 0.094$) than for the full-size-original condition.

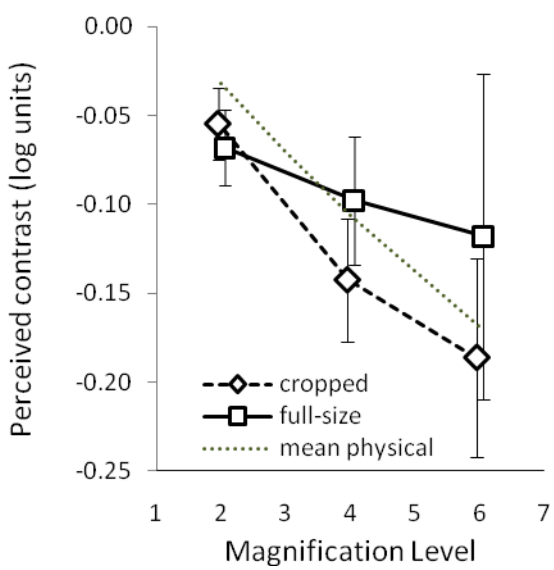

Figure 1. Experiment 1: Effect of electronic magnification (abscissa) with a fixed-luminance display background on perceived contrast (ordinate). Mean of 6 observers shown with 95% confidence limits[11]. Contrast units are log10 of the ratio of perceptually matched original and magnified contrasts. The perceived contrast is the difference between the perceived contrast of the match that had original-resolution and the contrast of the standard that was magnified. The effect of magnification was greater when the matching video was cropped to include only the magnified content. The dotted line shows the average physical difference in RMS contrast between the full-sized videos and respective magnified portions.

3.2 RMS contrast of central and global original video and of magnified video

It is unclear whether what was measured in this experiment was a perceptual effect or whether it was in fact a true physical difference in contrast between the magnified and original videos. The magnified videos only took content from the center of the originals, which were displayed in full. There is no reason to assume a priori that the center of a frame is always the highest-contrast region, or even that its contrast should match with its surround. In fact, in the sample of video clips used in this experiment, the average difference between full-sized and magnified video RMS contrasts (computed as the standard deviation of all pixel intensities in a video) was negative, of similar magnitude as the effects measured in the experiment, and increased in magnitude with increasing magnification (dotted line representing mean differences, Figure 1). That is, subjects in this condition appear to have been matching something correlated to the RMS contrast levels of the original and magnified videos. Note that RMS of the cropped original was equal to the RMS of the magnified video.

Subjects viewed and compared the stimuli freely, and were instructed to compare the entire area of the two videos. If subjects were actually able to directly compare the physical luminance distributions of the videos, as instructed, they would be expected to perform as indicated by the dotted lines in Figure 1 in the full-size condition, and the perceived contrast difference would be explained on a physical, rather than perceptual, basis. The physical RMS cannot explain the response in the cropped condition. On the other hand, subjects might be relatively insensitive to the raw luminance distribution (RMS contrast), and effect magnitude in this condition might be coincidental.

3.3 Interactions Between Display Background and Video Size

The results of Experiment 1 ran counter to our expectations. We expected that there should be an effect on perceived contrast of magnification, and that there were two potential causes should the effect be measured – a perceptual, or illusory, effect, and a physical effect (section 3.2). Either or both of these could cause the effects measured in Experiment 1, but cropping the original videos in should have removed the influence of any physical effect, and so perceived contrast attenuation should have been unchanged, reduced, or abolished. Instead, the perceived contrast effect was significantly increased. The cropped-original condition was intended to remove a potential factor in observer performance, but at the same time a confounding factor – the change in size, with magnification, of the original video – was introduced. Therefore, we suspected that changing the size of the original video was affecting its apparent contrast and that the apparent contrast difference between original and magnified stimuli was not actually due to reduction by magnification. Simultaneous contrast, where the apparent luminance of a test patch is dependent on the luminance of its surround or background, is known to be dependent on the spatial extent of the test and surround[10]. The phenomenon of simultaneous contrast has a straightforward impact in the current context: affecting the matching the luminance of the background to the luminance of the test videos.

3.4 Experiment 2: Matching Video and Background Luminance

Experiment 2 repeated the conditions of Experiment 1 (i.e. both cropped and full size original blocks were run in alternating order), except that now the luminance of the display background was matched, from frame-to-frame, with the mean luminance of the video stimuli. For the cropped condition, this meant that the entire display background was set at the same luminance, but for the full size condition, the original and magnified videos had slightly different mean luminance on any given frame, so the luminance of each video frame was matched by the luminance on the corresponding half of the screen. To further eliminate cues as to the difference in luminance between the two sides, and to reduce fine edge effects between the video clips and the background, Gaussian noise ($\sigma = 0.1$) was added to the background on each frame.

As shown in Figure 2, with the matched-luminance background (Experiment 2) there was again a reduction in the apparent contrast with increasing magnification (ANOVA main effect of magnification, $F_{2,10} = 6.04$, $p = 0.02$). For the smallest magnification level used (2x) the median apparent difference in contrast was -0.05 log units and for the greatest magnification level (6x) the median difference was around -0.10 log units for the full-size originals (squares in Figure 2) and was -0.04 log units for the smallest (2x) magnification and -0.06 log units for the largest (6x) magnification with the cropped originals (diamonds in Figure 2). Overall, for the cropped-original condition the effect was less than for the full-size-original condition (main effect of condition, $F_{1,5} = 26.5$, $p = 0.004$) but the effect of magnification was similar for the two conditions (magnification/condition interaction, $F_{2,10} = 1.67$, $p = 0.24$).

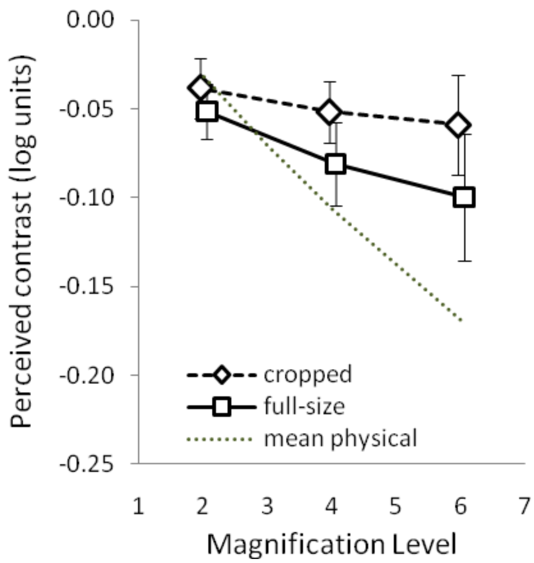

Figure 2. Experiment 2: Perceived contrast effects with frame-to-frame matched-luminance display background. Mean of the same 6 observers as in Experiment 1 is shown. The effect of magnification was less than in Experiment 1 (fixed-luminance background), but, in this case, greater for the full-sized-original condition than for the cropped-original condition. Confidence limits computed as in Figure 1.

3.5 Discussion

The removal of simultaneous contrast artifacts reveals that there is a significant residual effect of video magnification on perceived contrast. When identical (but for size change) stimuli are compared at a moderate magnification level (6x), as in the cropped condition, magnified video contrast appeared attenuated by about 0.05 log units (Figure 2, diamond symbols). Including additional, unmagnified content in the original comparison stimuli increased the apparent contrast attenuation by about another 0.05 log units (Figure 2, square symbols), and this additional difference was likely due to actual physical differences in contrast between the videos compared.

Thus, we see that magnified video appears to have decreased contrast relative to the same video presented at its original resolution. Though we have demonstrated that this effect has a significant perceptual component, we have not addressed the relationship between sharpness and contrast; that is, particularly for naive observers, judgments of high and low contrast are related with judgments of sharpness and blur. Furthermore, this is not necessarily a mistaken conflation of distinct properties, since perceived contrast and contrast sensitivity are both related perceptually with spatial frequency, which by definition is shifted by magnification. With the magnified videos, the absence of content beyond the original resolution becomes visible with increasing magnification – i.e. the video pixels become visible. This absence of content related high spatial frequencies in the magnified image is the likely cause of the illusory difference in contrast between magnified and original videos. We tested this hypothesis by varying the distance of subjects from the display, thus varying the visibility of the high spatial frequency cutoff in both the magnified and the original videos.

4. EFFECTS OF VIEWING DISTANCE

4.1 Experiment 3: Varying Viewing Distance

Subjects viewed the display in separate blocks at distances of 1, 3, or 5m. At each viewing distance, a single magnification (3x) was used, with trials randomly interleaved in six separate staircases. Viewing distance order was randomized between subjects. Original videos were full-sized or cropped in separate blocks, as in Experiments 1 and 2. Full size (360x360px) videos subtended with increasing distance 9.8°, 3.3°, and 2.0°; cropped (120x120px) videos subtended 3.3°, 1.1°, and 0.65°. To avoid the effects of simultaneous contrast between test and background as found in Experiment 2, the display background was again matched to the mean luminance of the stimulus videos, and filled with low-contrast Gaussian noise.

Figure 3a shows that with increasing viewing distance, the difference in perceived video contrast decreases for both comparison conditions (ANOVA main effect of distance, $F_{2,8} = 11.3$, $p = 0.005$), with a greater effect of viewing distance on the cropped-original condition (condition/distance interaction, $F_{2,8} = 7.59$, $p = 0.014$). At a distance of 5m, there was still some apparent contrast difference when the original video was full sized, which is consistent with the physical difference in contrast discussed in Section *3.2*. The difference was reversed at 5m when the cropped originals were used as comparisons, which is consistent with image blur being the cause of the residual perceived contrast difference at shorter distances.

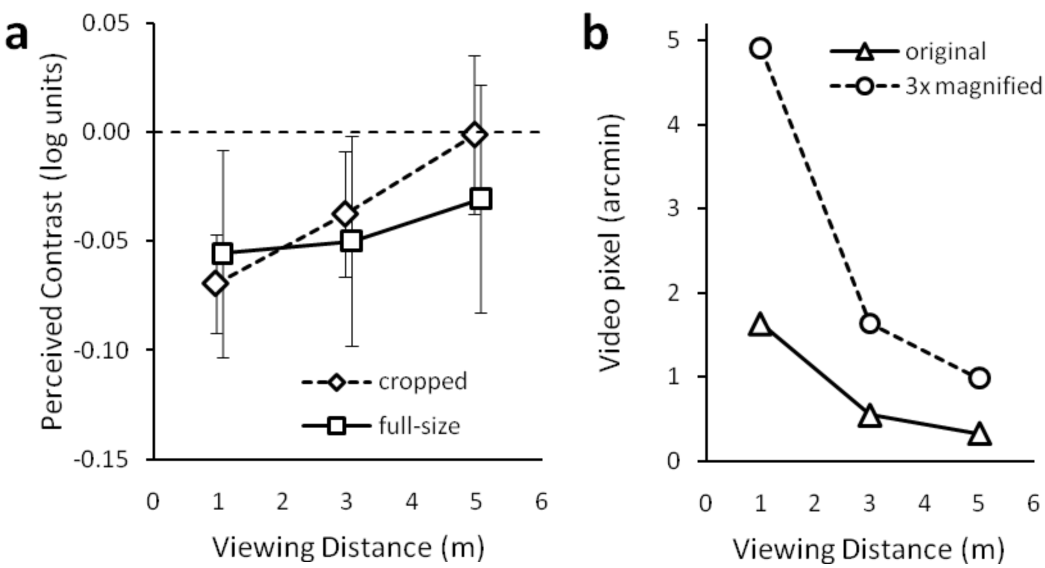

Figure 3 a) Effect of magnification on perceived contrast of video at three viewing distances, for cropped and full-sized original comparison conditions. For both conditions, the perceived difference in contrast between normal and magnified videos diminishes with viewing distance, much more so for the cropped than the full-sized conditions. At the 5m viewing distance, the perceived difference in contrast is eliminated when the original videos are cropped. Confidence limits computed as in Figure 1. b) Video pixel separation for original-resolution and magnified videos at the three viewing distances. Normal human acuity limits visual resolution of video detail to around 1 arcmin.

To understand why this is so, consider that magnified video pixels at 1m were 4.91 arc minutes apart, and therefore discernable to an observer sensitive to spatial frequencies as low as 12.2cpd. At 5m, the same magnified video pixels were 0.98 arc minutes apart, which would require sensitivity to spatial frequencies as low as 61.1cpd, which is beyond the limits of normal human acuity (Figure 3b). At this distance, then, both original and magnified videos should have looked equally sharp (though they were of different sizes in the cropped original condition). Furthermore, content in the original resolution videos was lost even at the 3m viewing distance, so that their apparent contrast would have been expected to decrease with distance – at 5m the magnified videos actually had similar apparent contrast as the originals when identical content was being compared as in the cropped original condition (Figure 3b).

4.2 Discussion

The decline with distance of the magnification effect on apparent contrast is caused by the decrease in visibility of the video pixelation. An additional effect of magnification, relatively constant with distance, is caused by the mismatch in physical contrast between whole videos and their central subregions.

5. GENERAL DISCUSSION

Two central findings were presented in the results of our experiments. First, there is a measurable difference in the apparent contrast of a video clip and a spatial subregion of the same clip. This difference is more when the subregion is magnified to the same size as the original (Experiments 2,3). Second, there is an illusory attenuation of apparent contrast for magnified video clips which can be attributed to the blurring or pixelation caused by the magnification (Experiment

3). A more peripheral, but still notable finding is that simultaneous contrast between a video clip and its background can be confused involuntarily by observers for the contrast of the clip itself (Experiments 1,2).

The results of these experiments support the hypothesis that perceived contrast of a complex visual stimulus amounts to a combination of contrasts across both space and across the spatial frequency domain. Spatial combination is demonstrated by the effect of including content in the original resolution videos that is not magnified in the comparison videos – in every experiment using this stimulus arrangement, the magnified videos were judged as being of lower contrast than the originals. However, magnified video contrast was not underestimated relative to the originals to the degree predicted if subjects were directly comparing the global RMS contrasts of the two videos (i.e. data did not track with the dotted line in Figure 2) – this could be due to subjects' making relatively more comparisons between identical structures in the two videos, and relatively ignoring the contrasts of non-magnified areas in the original, contrary to the perhaps difficult-to-follow instructions of the experimenters.

The effect of spatial frequency combination is demonstrated by the persistence of a perceived difference in contrast even when the non-magnified content is not included in the original video, and the disappearance or reversal of this difference at large viewing distances. The persistence of the effect is explained as the perceived lack of high-frequency contrasts in the magnified video, i.e. blurring – this effect disappears at large viewing distances because there is no longer a lack of high-frequency contrast. The effect is eliminated for some observers at large viewing distances presumably because much image content is now 'lost' beyond the acuity limit, and so the amount of contrast perceived across the frequency domain is less than with the magnified image, whose spectrum is now comfortably fit within the viewer's range of sensitivity.

6. SUMMARY

Magnified video is perceived as having lower contrast than normal-resolution video for two reasons: First, because regions of an image tend to have lower physical contrast than the larger image by conventional measures; second, because the magnified image is perceptually blurred, and is seen as lacking in high spatial frequency contrasts. Such lack of sharpness is interpreted as loss of contrast as in many situations. Caution is to be taken in measuring perceived video contrast against a background of fixed mean luminance.

7. ACKNOWLEDGEMENTS

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