

Perceptual evaluation of JPEG coded stereoscopic images

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ABSTRACT

JPEG compression of the left and right components of a stereo image pair is a way to save valuable bandwidth when transmitting stereoscopic images. This paper presents results on the effects of camera-base distance and JPEG-coding on overall image quality, perceived depth, perceived sharpness and perceived eye-strain. In the experiment, two stereoscopic still scenes were used, varying in depth (three different camera-base distances: 0, 8 and 12 cm) and compression ratio (4 levels: original, 1:30, 1:40 and 1:60). All levels of compression were applied to both the left and right stereo image, resulting in a 4x4 matrix of all possible symmetric and asymmetric coding combinations. We applied the single stimulus method for subjective testing according to the ITU 500-10 recommendations. The observers were asked to assess image quality, sharpness, depth and eye-strain. Results showed that JPEG coding had a negative effect on image quality, sharpness and eye-strain but had no effect on perceived depth. An increase in camera-base distance increased perceived depth and reported eye-strain but had no effect on perceived sharpness. Furthermore, both sharpness and eye-strain correlated highly with perceived image quality.

Keywords: stereoscopic images, asymmetric/symmetric JPEG coding, image quality, depth, sharpness, eye-strain.

1. Introduction

Over the years much effort has been spent on realizing digital image compression to obtain savings in bandwidth and storage capacity. The same compression techniques used in two-dimensional image material can also be applied independently on the left and right view of a stereo image pair. In order to evaluate the effect of compression techniques on perceived image quality, 2D objective measures such as the peak-signal-to-noise ratio (PSNR) or the root-mean-squared error (RMSE) are often used. The outcome of these measures do not necessarily correspond with the outcome of subjective tests regarding image quality^{3,4}. These measures indicate only the difference between the coded and original image. In order to get a better understanding of the relation between the introduced coding artifacts and the perceptual attributes of an image, subjective testing is required. In this paper we evaluate a number of relevant perceptual attributes regarding symmetric and asymmetric JPEG coding of stereoscopic images. First we will discuss previous research on perceived image quality, perceived depth, perceived sharpness and perceived eye-strain regarding 3D television. Subsequently, we will describe an experiment where we have manipulated camera-base distance and JPEG coding level and have measured the effects on perceived quality, sharpness, depth and eye-strain.

Subjective image quality is a standard psychological criterion used to evaluate imaging systems. It is a subjective preference judgement which is widely used to compare for example coding algorithms, image processing techniques, and system configurations. Image quality is regarded as a multidimensional psychological construct, based on several attributes. In case of stereo images no comprehensive stereoscopic image quality model had been formulated to date, yet it is likely that attributes such as depth, sharpness, colour, motion rendition, flicker, and eye-strain contribute to the perceived stereoscopic image quality.

The storage and transmission of 3D material involves a large amount of data. Therefore it is necessary to apply coding techniques such as JPEG or MPEG coding to reduce the used bandwidth. Based on theories of binocular suppression, it is assumed that the binocular percept of a stereo image pair is dominated by the high quality component. Thus, when one image of the stereo pair is compressed such that a high quality is maintained, the other view can be coded more heavily without introducing visible artifacts in the binocular percept. The mixed resolution concept was introduced by Perkins¹. Mixed resolution coding assumes that the binocular percept is not affected when one view is of high quality and the other view of lower quality. Perkins applied low-pass filtering as compression algorithm resulting

in a high-resolution and a low-resolution image for each view of a stereo image pair. The author concludes that mixed-resolution coding is easy to implement, and the reduction of the bit rate is significant with respect to a system that employs no coding. Another method based on asymmetric coding was proposed by Reynolds and Kenyon². The authors used wavelet transformation coding to obtain a detailed high resolution image while the other view is a lower resolution image. Chen et al.⁵ investigated the effect of JPEG coding on the subjective image quality of stereoscopic images. The authors concluded that unacceptable quality for still 2D images at a certain compression rate can be acceptable for the stereoscopic version of the same scene with the same compression rate. Stelmach and Tam⁶ and Tam et al.⁷ applied a different compression ratio on the left- and right-eye views of a stereoscopic sequence using MPEG-2. In the experiment of Stelmach and Tam⁶, subjects rated the overall subjective image quality of the sequence while the left-eye view was displayed at a higher resolution than the right-eye view. The results showed that the subjective image quality of a stereo sequence was approximately the average of the monoscopic quality of the left- and right-eye images. The results of the experiment of Tam et al.⁷ showed the correlation between image quality, sharpness and depth. The experimental results showed a high correlation between subjective image quality and sharpness and a low correlation between image quality and perceived depth, so image quality of coded images was mainly influenced by sharpness, and less so by perceived depth. The asymmetric MPEG-2 coding results of Stelmach and Tam⁶ showed resemblance with basic research on binocular vision⁸. The human visual system weighs incoming information from both eyes when arriving at a final percept.

Depth perception of displayed objects is formed by monocular cues (luminance, shading, accommodation, shadows, perspective, size, etc.) and binocular cues (vergence and retinal disparity). The use of disparity information produces a compelling sense of depth, which defines the added value of stereoscopic TV. IJsselsteijn et al.⁹ investigated the perception of depth and the naturalness of depth when viewing stereoscopic image material. As soon as binocular disparity was introduced, the ratings of perceived depth and naturalness of depth increased. Tam et al.⁷ investigated perceived depth for stereoscopic images and non-stereoscopic images. Viewers also rated perceived depth of asymmetric MPEG-2 coded sequences at 6, 3, and 1 Mbits/s. The results show that the addition of disparity information to non-stereoscopic video sequences enhanced the experience of depth. The sensation of depth was higher in stereoscopic sequences at all bit rates as compared to monoscopic sequences. The perceived depth in stereoscopic sequences did not depend on the visibility of MPEG-2 coding artifacts. When the bit-rate was reduced from 6 Mbits/s to 1 Mbits/s, the perceived depth dropped in a similar way for both stereo and non-stereo sequences. Stelmach et al.¹⁰ investigated the effect of spatial and temporal low-pass filtering on perceived depth. The results indicate that spatial low-pass filtering has no effect on perceived depth. Temporal low-pass filtering produced poor image quality but the sensation of depth was relatively unaffected. An explanation is that low-pass filtering leaves the low spatial frequencies, that are sufficient to carry the disparity signal, unaffected. In their studies, depth shows a weak correlation with image quality and sharpness. These results suggest that depth is a dimension of perceptual experience that is largely independent of sharpness and overall image quality. This is not in line with the results of IJsselsteijn et al.¹¹ where perceived image quality could be expressed as a function of perceived depth and experienced eye-strain. These results were obtained using uncompressed images that varied in terms of camera-base distance, convergence distance, and focal length. A number of stimuli contained excessive disparities, thus making it likely for subjects to base their quality judgements on different image attributes than with the Stelmach¹⁰ study.

Perceived sharpness in stereoscopic images can be affected by several parameters e.g. camera defocus, coding, binocular disparity. One would expect that introducing disparity information in a stereo image would sharpen the edges by reducing positional uncertainty. Berthold¹² reported that stereo images with different degrees of gaussian blur were perceived sharper than non-stereo images. Tam et al.⁷ found that the subjects rated the MPEG-2 coded stereo and non-stereo images equally sharp or the stereo images even slightly less sharp. A high correlation was found between sharpness and image quality in both studies. Stelmach et al.¹⁰ investigated the effect of mixed-resolution on perceived sharpness and concluded that spatial low-pass filtering gives an acceptable sharpness. Sharpness was biased towards the eye with the greater spatial resolution. On the other hand, temporal low-pass filtering produced very poor images with blurred edges. Meegan et al.¹³ confirmed these findings in an experiment measuring the visibility of blur in asymmetric processed stereo images. When the lower quality view contained blur artifacts, the higher quality view was over-weighted by the visual system. There was no effect of eye-dominance on the occurrence of over-weighting in blur matching. So, blur seems to be an acceptable form of monocular degradation.

Many studies report a clear preference for stereoscopic images over non-stereoscopic ones. However, viewing stereo images can be more fatiguing than viewing conventional two-dimensional images. Because eye-strain is a

potential health hazard, it is important to have an understanding of its subjective magnitude and impact on the user. IJsselsteijn et al.¹¹ investigated the effect of stereoscopic filming parameters and display duration on the subjective assessment of eye-strain. The averaged results of the eye-strain ratings show a clear linear increase with increasing disparities. There was no significant effect of display duration on the eye-strain scores, but the display durations were relatively short (1-15 seconds). Mitsuhasi¹⁴ found that observers experienced more eye-strain for binocular vision than with the conventional television picture, using an objective measure known as the critical flicker frequency. Critical flicker frequency is the frequency at which flicker just begins to be perceptible as the frequency gradually decreases from being invisible. Okuyama¹⁵ evaluated visual fatigue with visual function testing (objective measure) and interviews (subjective measure). Visual function testing showed a mismatch between convergence and accommodation. The interviews reported more eye pain, an alien feeling in the eyes and eyes filled with tears. Both evaluations show an increase in visual fatigue. Kooi and Lucassen¹⁶ concluded that disparity, crosstalk and blur are the most important parameters that cause eye-strain.

We performed an experiment to investigate the effect of symmetric/asymmetric JPEG coding on perceived depth, sharpness, image quality and eye-strain. Further, we want to investigate the effect of camera-base distance on perceived depth, sharpness, image quality and eye-strain. Finally, we want to check if there is an effect of eye dominance on the attribute ratings. In other words, whether the dominant eye is over-weighted in the overall attribute rating. Hashim¹⁷ investigated 2500 patients at the Optimax Laser Clinic and found that 68% of the people were right dominant and 32% of the people were left dominant. Compared to previous experiments on asymmetric coding, we controlled the camera-base distance and investigated the effect of JPEG coding on perceived eye-strain as well as the effect of eye-dominance on the attributes.

2.Method

2.1. Observers

Thirty-two naïve observers were paid to participate in this experiment. They were divided in 4 groups assessing 1 attribute per group, i.e. a between-subjects design. The attributes to be assessed in this experiment were perceived sharpness, perceived depth, perceived image quality and perceived eye-strain. The observers, mostly students, came from the same age group (18-27 years old). All participants had a visual acuity of ≥ 1 , good stereo vision (as tested with the Randot stereo test) and good colour vision (as tested with the Ishihara test). Eye dominance and inter-pupillary distance were also measured. Seventy-four percent of the subjects were right dominant and the average inter-pupillary distance was 6,2 cm.

2.2. Materials

EQUIPMENT

An AEA-Technology stereoscopic display was used in this experiment to display the stereoscopic material. The AEAT system consists of two Barco CPM 2053FS colour monitors mounted perpendicular to each other (see Fig 1). The dual monitor system displayed the right and left image at the same time using a half see-through mirror and polarization filter in front of each screen. The observers wore polarized glasses in order to provide each eye with a single view. A SUN ISP system provided the Barco monitors with a video signal. Custom built software was used to control the display duration and synchronized the output of the 2 codecs transferring the images.

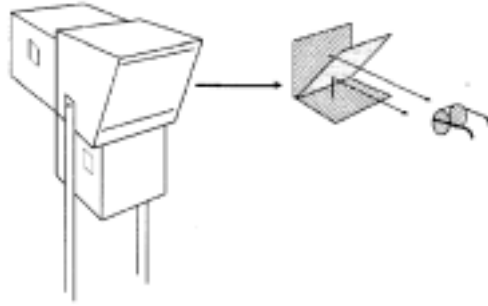


Fig 1. The AEAT system consisting of two Barco monitors displaying the left and right eye images at the same time. The polarized glasses are used to separate the left and right views.

STIMULI

The image material used in this experiment consisted of two still scenes, *playmobiles* and *bureau*, that varied in camera-base distance and compression ratio. The scene *playmobiles* consists of a colourful toy landscape with mountains in the background and numerous playmobiles in the foreground. The scene *bureau* consists of a tailor's dummy sitting behind a desk on which some office equipment is located. The original scenes are shown in figure 2.

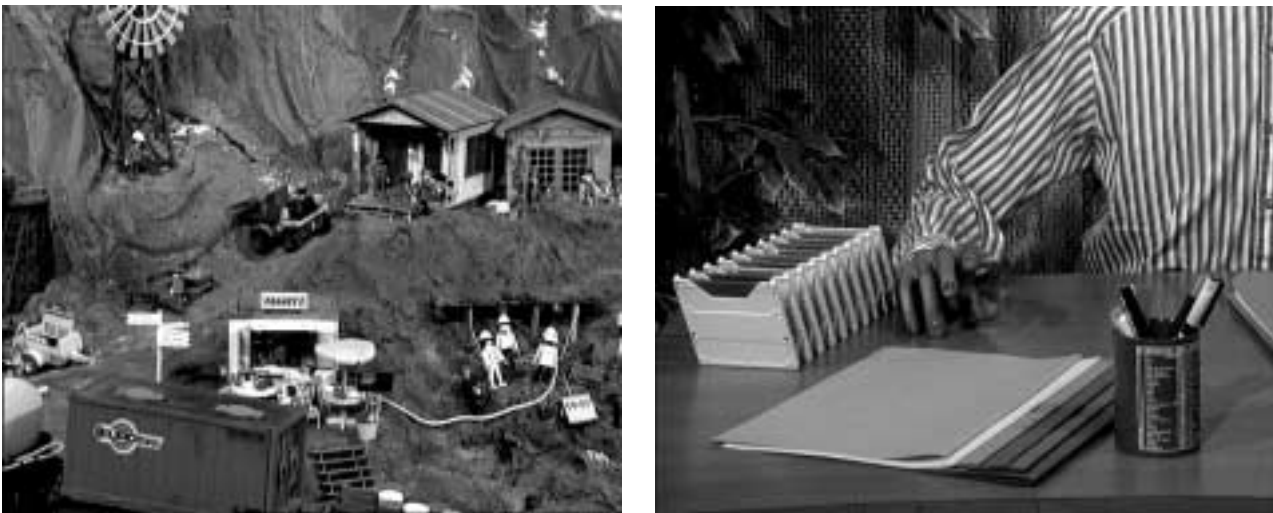


Fig 2. The left panel shows the original of the scene *playmobiles* and the right panel shows the original of the scene *bureau*.

For each scene, focal length and convergence distance were fixed to 20 mm and 1.30 m, respectively. Each scene was recorded at three different camera-base distances, namely 0 cm (i.e. monoscopic), 8 cm and 12 cm. An increase in camera-base distance results in an increase in disparity values and thus perceived depth, while the size of the objects and the field of view remains constant. A camera-base distance of 0 cm introduces no disparity between the left and the right image and thus no perceptible stereoscopic depth, while depth is highly noticeable with a camera-base distance of 8 cm and 12 cm.

The stimulus set contained the original, uncompressed version, of each scene and three JPEG coded versions with a JPEG compression factor of approximately 1:30, 1:40 and 1:60. This corresponds with a JPEG Q-parameter of 30, 20 and 10 for the scenes *playmobiles* and *bureau*. Stereo image pairs were formed by symmetric or asymmetric coding of the left and right eye images. In a symmetric stereoscopic image pair the same compression ratio is applied to the left and right components. In asymmetric coding the compression ratio of the two components are different. Table 1 gives the bytes per pixel (bpp) of the separate component of a stereo pair and the bpp of the symmetric and asymmetric image pairs, which is the averaged bpp of the left and right eye components.

Table 1. Bpp and the compression ratio for the JPEG coded images

Q-parameter	bpp	Compression Ratio	Stereoscopic image bpp		Left Eye			
					Org	Q30	Q20	Q10
Org	3.00	1:1	Right Eye	Org	3.00	1.55	1.54	1.53
Q30	0.11	1:30		Q30	1.55	0.11	0.095	0.08
Q20	0.08	1:40		Q20	1.54	0.095	0.08	0.065
Q10	0.05	1:60		Q10	1.53	0.08	0.065	0.05

In order to test eye dominance, each combination of bit-rates was presented to both eyes. Each JPEG coding level was displayed an equal number of times to each eye (left and right) and all combinations of the coding levels were presented once. Thus in total, 2 scenes, 3 camera-base distances and 4 coding levels were used. This resulted in a stimulus set of $2 \times 3 \times 16 = 96$ images.

2.3. Procedure

A set of 96 stereoscopic images were presented sequentially to the observers and rated according to the single stimulus scaling method. Each attribute was rated by a different group of 8 observers and each observer rated only one attribute. The perceived overall *image quality* was rated on a quality category scale from 1 up to 5 corresponding with 1 for bad image quality and 5 for excellent image quality. The scale was labeled with the adjective terms [bad]-[poor]-[fair]-[good]-[excellent] according to the ITU Recommendations¹⁸. Perceived *sharpness* was rated on an impairment scale from 1 up to 5. The least sharp image corresponded with 1 and the sharpest image with 5. Experienced *eye-strain* was rated on an impairment scale from 1 up to 5. The least experienced eye-strain should be rated with 1 and the heaviest experienced eye-strain with 5. The adjective terms of the scale were [imperceptible]-[perceptible, but not annoying]-[slightly annoying]-[annoying]-[very annoying]. Perceived *depth* was rated on a numerical scale from 1 up to 5. The image with no perceived depth was to be rated 1 and the image containing most perceived depth was to be rated 5.

The stimulus set of 96 images was judged for each attribute in two subsessions, containing 48 stimuli each, with a small break in between. Each subsession of 48 images took approximately 20 minutes. Before the experiment started the observers were asked to read the instructions explaining the task and attribute they had to rate. After that the observers participated in a trial of 16 stimuli to get acquainted with the stimulus set and the range of the variations in quality, sharpness, depth or experienced eye-strain.

3.Results

3.1. Eye dominance

The effect of eye dominance was tested for the asymmetric combinations and their reverse version per attribute. As tested with a Wilcoxon Signed Rank Test, which is a conservative test, there were no significant differences between the ratings of the asymmetric combinations and their reverse version per attribute. I.e., the rating for the combination Q10_Q20 did not significantly differ from the rating for the combination Q20_Q10 for all subjects and all attributes. Therefore we pooled these asymmetric ratings in order to get a bigger data-set.

3.2. Perceived Image Quality

Figure 3 shows the averaged image quality scores and the standard errors for the scenes *playmobiles* and *bureau*. On the x-axis the symmetric and asymmetric coding combinations of the left and right view of the stereoscopic images are presented in increasing bit-rate. The image quality score of an asymmetric coding combination is the average of two asymmetric combinations because there was no significant difference between them. For instance the score for 10_20 represents the average of the stereo pair with Q10 viewed by the left eye and Q20 viewed by the right eye and visa versa. The y-axis represents the quality scores from 1 (bad) to 5 (excellent). The three lines in the figure represent the 3 camera-base distances 0, 8 and 12 cm.

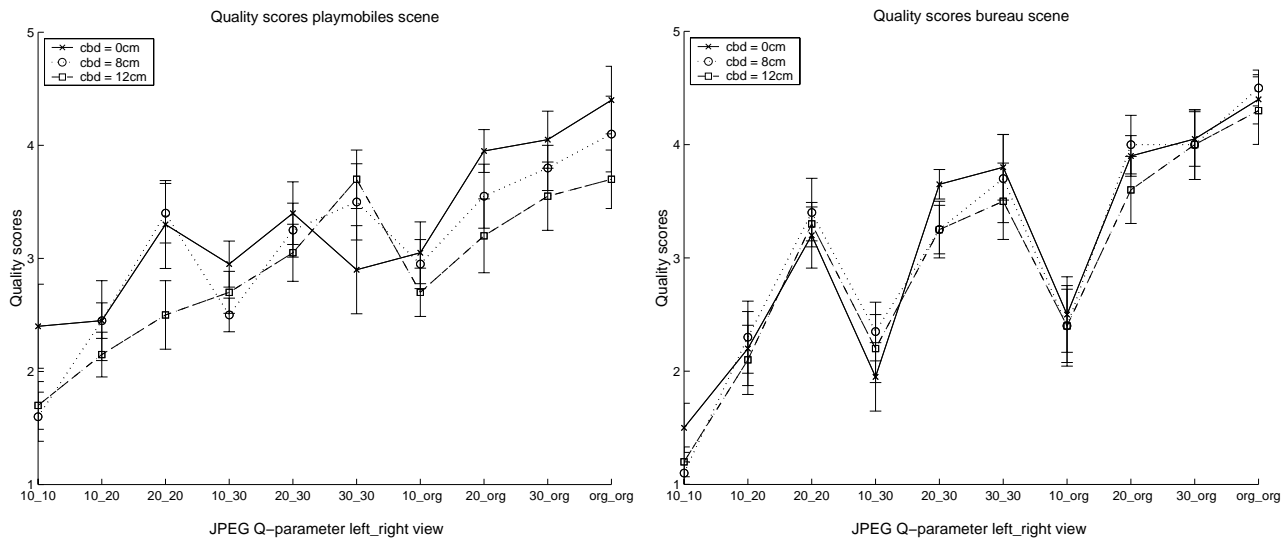


Fig 3. Averaged image quality scores with the error bars for the scenes *playmobiles* and *bureau*. The x-axis represents the JPEG Q-parameter for the left and right view and the three lines in the figure represent the 3 camera-base distances.

The quality scores show an increasing trend with increasing bit-rate for both scenes. Remarkable are the two quality dips in the *bureau* scene. At these points one of the two views of the stereoscopic image is coded with a JPEG compression factor of Q10. This image contains a lot of annoying artifacts (mostly blockiness) which can hardly be reduced by the high quality component of the stereoscopic image pair. The *bureau* scene contains some homogeneous areas where the blockiness artifact is more visible. The quality dip in the *playmobiles* scene, containing less homogeneous areas, is smaller but also at Q10. An increase in camera-base distance (cbd) has almost no effect on perceived image quality. The *bureau* scene shows almost no differences between the three camera-base distances and the quality judgements of the scene *playmobiles* differs only slightly.

The weighting of bi-ocular inputs (left and right view) in binocular combination was also investigated. When the left and right view of an asymmetric coding pair are viewed separately, the less compressed view would have a high subjective image quality. On the other hand, the highly compressed view would have a low subjective image quality, and JPEG coding artifacts are visible. In figure 4, the image quality of the symmetric inputs (high quality and low quality of the views) are presented by the whiskers (endpoints) and the asymmetric combination (stereo view of the high and low quality inputs) is presented by the height of the bar. The image quality of the symmetric inputs is the bi-ocular combination of two images with the same compression ratio. Figure 4 presents the symmetric and asymmetric stereoscopic image pairs of the *bureau* scene with a camera-base distance of 12 cm. The x-axis represents the asymmetric coding combinations and the y-axis represents the image quality score of the asymmetric JPEG coded stereoscopic image pairs and their corresponding symmetric image pairs consisting of equally JPEG coded components. The height of the bars represents the judged image quality of the asymmetrically coded JPEG images (e.g. Q10_Q20). The boxes marked as 'H' represent the judged image quality of the corresponding symmetric image pair when the high

quality component of the asymmetric pair is shown to both eyes (e.g. Q20_Q20). The boxes marked as 'L' show the image quality if the low quality component of the asymmetric image pair is shown to both eyes (e.g. Q10_Q10).

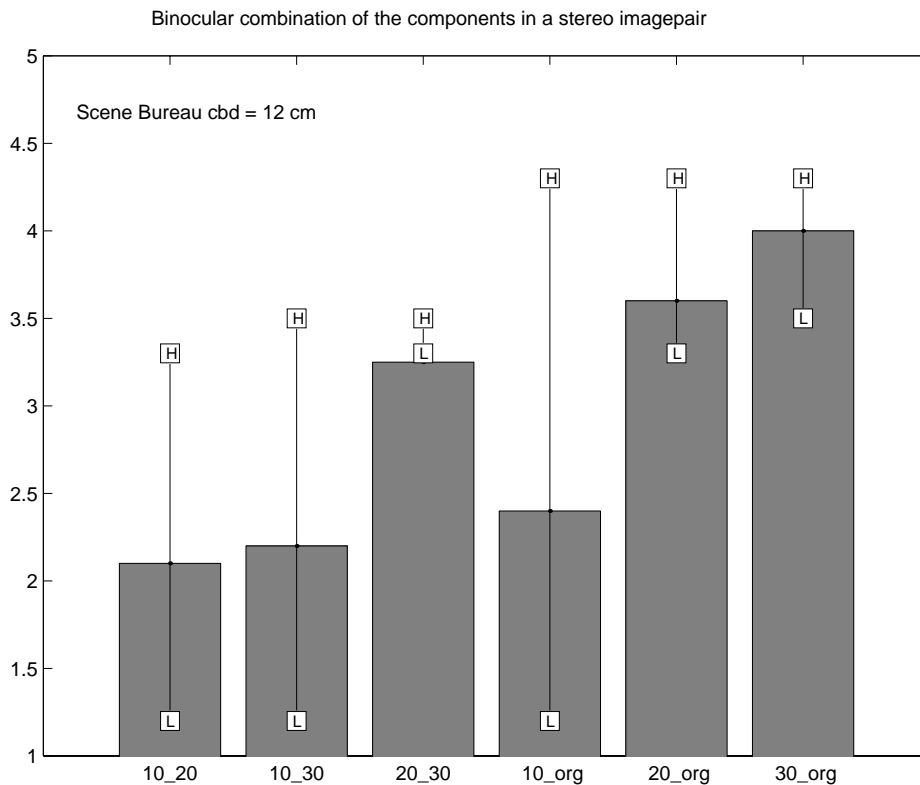


Fig 4. Binocular weighting of image quality for the scene *bureau* with a camera-base distance of 12 cm. In the first case labeled as 10_20 on the x-axis, the judged image quality of the symmetric image pairs are labeled as 'L' and 'H' corresponding to JPEG coding Q10_Q10 and Q20_Q20. The judged image quality of the asymmetric image pair is the height of the bar (Q10_Q20).

The results of figure 4 show that the perceived image quality of the binocular combination ends somewhere just below the average of the bi-ocular high quality and low quality input. The graph has a tendency towards the low quality input. This may be due to the fact that in the lower compression images the blockiness artifact is highly visible. There are some differences between the scenes but these are small. The tendency towards the low quality input is a bit stronger in the *bureau* scene than in the *playmobiles* scene when Q10 is in the asymmetric image pair. This can be explained by the fact that the blockiness artifact is more visible in the *bureau* scene at high compression rates because there are more homogeneous areas.

3.3. Perceived Depth

The perceived depth scores and the error bars for the *playmobiles* and *bureau* scene are presented in figure 5. The x-axis represents the symmetric and asymmetric coding combinations of the left and right image in increasing bit-rate. The y-axis represents the depth scores from 1 (no perceived depth) to 5 (maximum perceived depth).

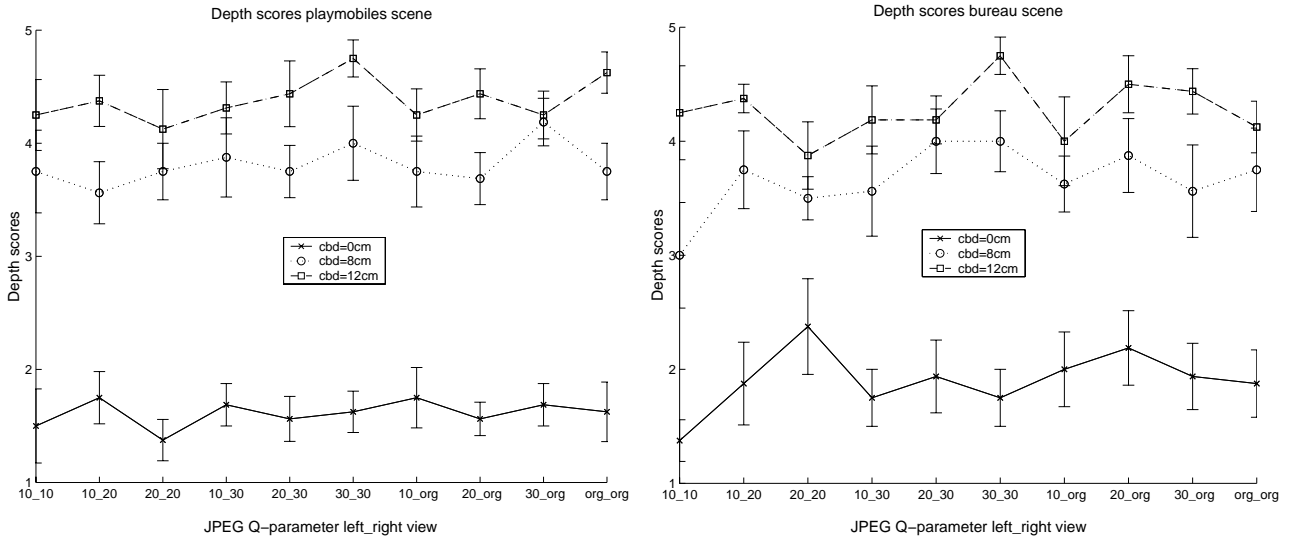


Fig 5. Averaged depth scores with the error bars for the scenes *playmobiles* and *bureau*. The x-axis represents the JPEG Q-parameter for the left and right view and the three lines in the figure represent the 3 camera-base distances. The y-axis shows the judged depth.

As expected, the perceived depth scores increased when the camera-base distance increased. The perceived depth between camera-base distance 8 and 12 cm increased less than between 0 and 8 cm. Furthermore, JPEG coding had no effect on perceived depth. For all JPEG compression levels and combinations, the perceived depth remains nearly the same for each camera-base distance.

3.4. Perceived Sharpness

In figure 6 the sharpness plots of the *playmobiles* scene and the *bureau* scene are given. The x-axis represents the symmetric and asymmetric coding combinations of the left and right image in increasing bit-rate. In this case, the y-axis represents the perceived sharpness scores from 1 (blurred) to 5 (sharp).

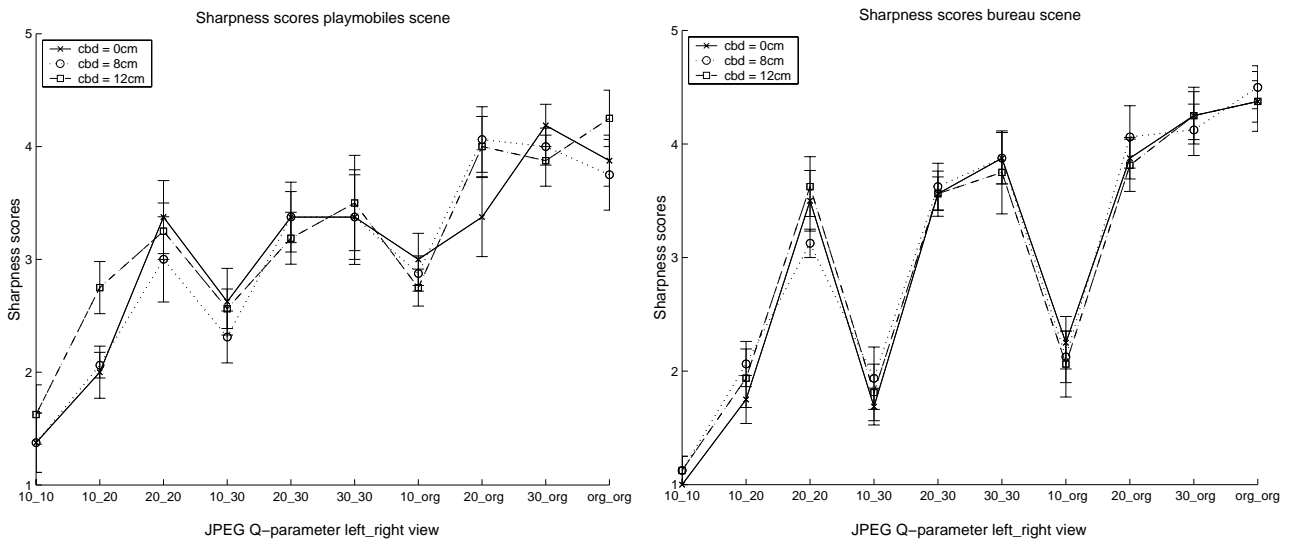


Fig 6. Averaged sharpness scores with the error bars for the scenes *playmobiles* and *bureau*. The x-axis represents the JPEG Q-parameter for the left and right view and the three lines in the figure represent the 3 camera-base distances. The y-axis shows the judged sharpness.

The results for perceived sharpness show great similarity with the perceived image quality results. Perceived sharpness increased when the bit rate increased. Also in these figures the perceived sharpness scores dropped dramatically as soon as JPEG compression level Q10 was presented in one of the two views of the stereoscopic pair. The sharpness scores in the *bureau* scene were approximately the same for the three camera-base distances. There were little differences visible in the *playmobiles* scene between the three camera-base distances. So, introducing image disparity has no effect on perceived sharpness.

3.5. Perceived Eye-strain

Figure 7 represent the eye-strain scores of the subjects. The 5-grade impairment scale was used running from 1 (very annoying) to 5 (imperceptible).

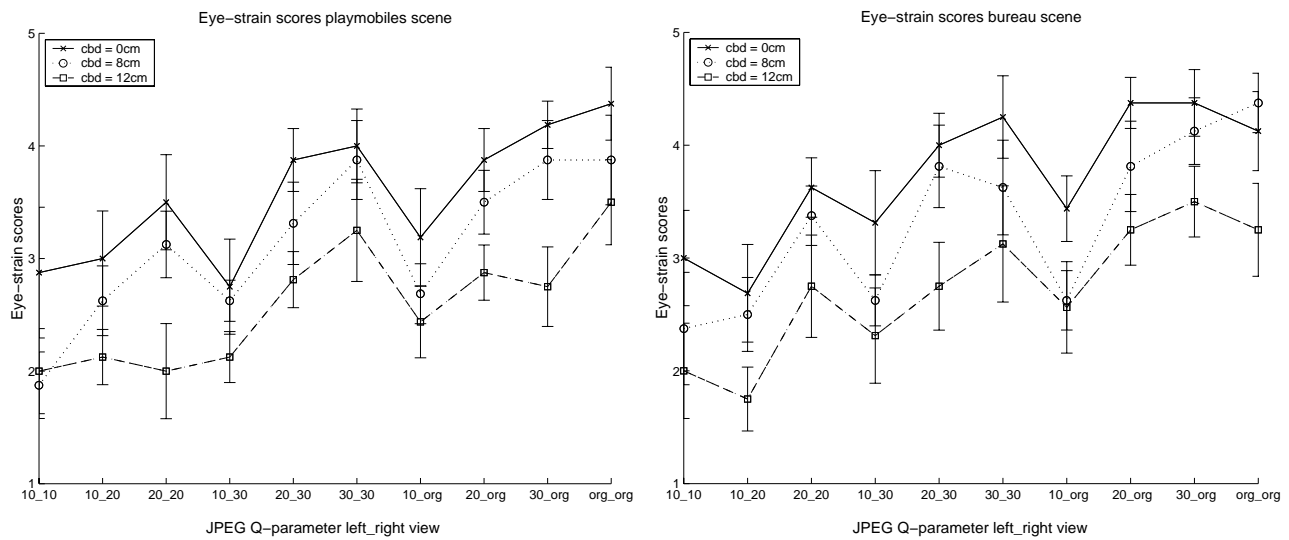


Fig 7. Averaged eye-strain scores with the error bars for the scenes *playmobiles* and *bureau*. The x-axis represents the JPEG Q-parameter for the left and right view and the three lines in the figure represent the 3 camera-base distances. The y-axis shows the eye-strain scores.

The figures show less annoyance with increasing bit-rate and more annoyance with increasing camera-base distance. As in the quality and sharpness figures, there is an increase in reported eye-strain as soon as JPEG coding level Q10 is presented in one of the two views of a stereoscopic image pair.

3.6. Correlation between attributes

In this experiment we found high correlations between image quality and sharpness ($r=0.94$) and between image quality and eye-strain ($r=0.79$). No significant correlation was found between image quality and depth as can be deduced when comparing figures 3 and 5. In figure 8 the scatter plots of the average scores of the attributes are shown for each combination of JPEG coded stereo images and for all three camera-base distances.

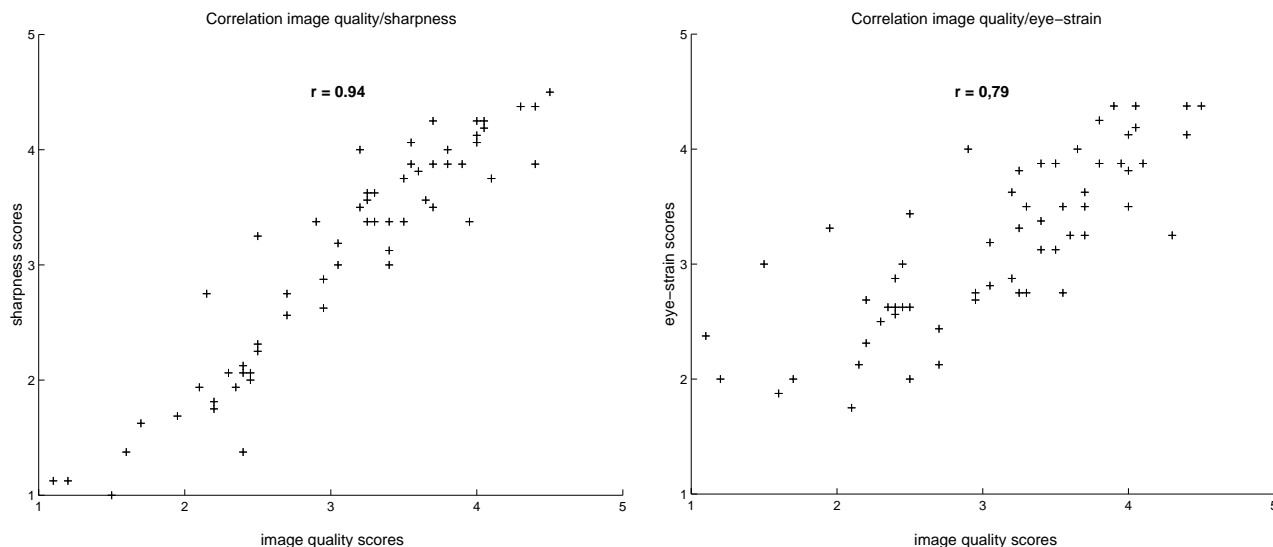


Fig 8. Scatter plots of the attributes with a high correlation.

4. Discussion

An increase in JPEG compression decreased the perceived image quality and an increase in camera-base distance had no effect on image quality. The asymmetric image coding resulted in a perceived image quality somewhere just below the average of the two symmetrically coded image pairs for the right and left view. The perceived depth scores increased when the camera-base distance increased. Furthermore, JPEG coding had no effect at all on perceived depth. An increase in JPEG compression decreased the perceived sharpness. The introduction of image disparity had no effect on perceived sharpness. The quality results and sharpness results showed a high correlation of $r=0.94$. The experienced eye-strain increased a little when JPEG compression increased and also with the increase of camera-base distance. Eye-strain also showed a high correlation with image quality ($r=0.79$).

The perceived image quality of monoscopic images (camera-base distance=0) was rated about the same as the stereoscopic images (camera-base distance=8,12). The reason for this finding may be that the added value of enhanced depth was not taken into account when judging image quality. This may be due to the used stimulus set and experimental paradigm. Stelmach¹⁰ found also a low correlation between image quality and perceived depth using low-pass filtering. IJsselsteijn et al.¹¹ described an empirical relation between perceived depth, eye-strain and image quality for *uncompressed* stereoscopic images. The authors showed that an increase in image quality ratings could be attributed to an increase in perceived depth (when kept within natural bounds). However, quality judgements were attenuated by the eye-strain ratings, thus arriving at a simple stereoscopic image quality model for uncompressed images, describing quality as the difference between the added value of depth diminished by experienced eye-strain. It seems reasonable that the attribute perceived depth is strongly associated with attributes such as naturalness and presence, so probably additional concepts are needed when attempting to measure the added value of depth.

The results of this experiment showed that an increase in JPEG coding decreases perceived image quality and sharpness and slightly increases perceived eye-strain. No effect of JPEG coding was found on perceived depth. Results of Stelmach¹⁰ showed that spatial low-pass filtering had no effect on perceived depth. In an earlier study, Stelmach⁶ showed that subjective image quality of a stereo sequence was approximately the average of the monoscopic quality of the left- and right-eye images. In this experiment, the stereoscopic image quality of the binocular combination ended approximately in the middle but tended towards the low-quality component of the stereoscopic picture. We also controlled the disparities and found no difference between 0, 8 and 12 cm. In our experiment the 'monoscopic situation' was the symmetric bi-ocular measurement of image quality at camera-base distance 0, 8 and 12 cm, whereas Stelmach⁶ used the monoscopic image quality measures on a 2D screen. The reason for the small tendency to the low image

quality component in binocular combination (particular at Q10) may be that the blockiness artifact is the main artifact in the image at high compression rates. These results are in line with Meegan et. al.¹³ who also found under-weighting of the high quality component when the blockiness artifact was present in the image. On the other hand, when blur is presented, the high quality view was over-weighted.

Camera-base distance had no significant effect on perceived image quality. In the *playmobiles* scene there were slight differences and in the *bureau* scene there were no differences. As expected, perceived depth increased with increasing camera-base distance. An increase in camera-base distance from 0cm to 8cm significantly increased the perceived depth. The increase from 8cm to 12cm resulted in a smaller increase in perceived depth. As in the image quality figures, an increase in camera-base distance had no effect on the perceived sharpness. This is slightly surprising because introducing disparity information in a stereo image would sharpen the edges by reducing positional uncertainty. The last attribute, eye-strain, also showed an increase when camera-base distance increased. This was also found by IJsselsteijn¹¹ where averaged results of the eye-strain ratings showed a clear linear increase with increasing disparities. Also the results of Kooi¹⁶ showed that increasing disparity is one of the most important parameters that cause eye fatigue.

When looking at the image quality figures it can be concluded that there is almost no decrease in image quality when coding at org_org, org_q30 and org_q20. The quality drops heavily when one of the views is coded with a JPEG compression of Q10. A stereoscopic image pair with compression Q20_Q20 has the same bit-rate (in this experiment) as an image pair with compression Q10_Q30. In figure 3, the image quality of Q20_Q20 is higher than the quality of Q10_Q30. This can be explained because the blockiness artifact is highly visible in Q10. So, asymmetric coding is a valuable way to save bandwidth but the JPEG compression of both views must be within an acceptable range.

In the near future we want to investigate the image quality percept more precisely and find out what concepts determine the perceived image quality. We think that the added value of depth is not taken into account when judging image quality. So, for the evaluation of 3D TV other concepts than image quality may be needed. The added value of 3D, namely the depth dimension, may be related to concepts of naturalness or presence, as has been argued by IJsselsteijn et al.^{9,19}

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