3DC Safety Guidelines for Dissemination of Human-friendly 3D

Revised on April 20, 2010
Conforms with international guidelines "ISO IWA3"

3D Consortium (3DC)
Safety/Guidelines Section

The "3DC Safety Guidelines" is a literal English translation of the Japanese version.
If translated guidelines cause problems, statements of the Japanese version are prioritized.

For full-fledged revision of the 3DC Safety Guidelines

April 2010, 3D Consortium (3DC) Safety/Guidelines Section

These guidelines were developed in December 2004 for the convenience of our members.

At that time, there were no publicly authorized guidelines for 3D images except the "Tentative Proposals for Guidelines Relating to 3D Images" by the Japan Electronics and Information Technology Industries Association published in June 1999.

In September 2005, efforts by related parties bore fruit as the International Workshop Agreement 3 (IWA3) was developed and published concerning image safety by the International Organization for Standardization (ISO).

In February 2006, the 3DC Safety Guidelines were revised to cover the contents related to 3D images in ISO IWA3 and to enhance contents. With this revision, reliability of these guidelines was significantly improved.

In November 2008, the 3DC Safety Guidelines were publicized to support the 3D industry with expectations for further development.

Thereafter, 3D movies produced in Hollywood captured the box office, commercialization of 3D TVs has been realized; and due to drastic evolution in techniques for shooting, production and display of images, particular parts of the safety guidelines have become ill-suited to the current techniques.

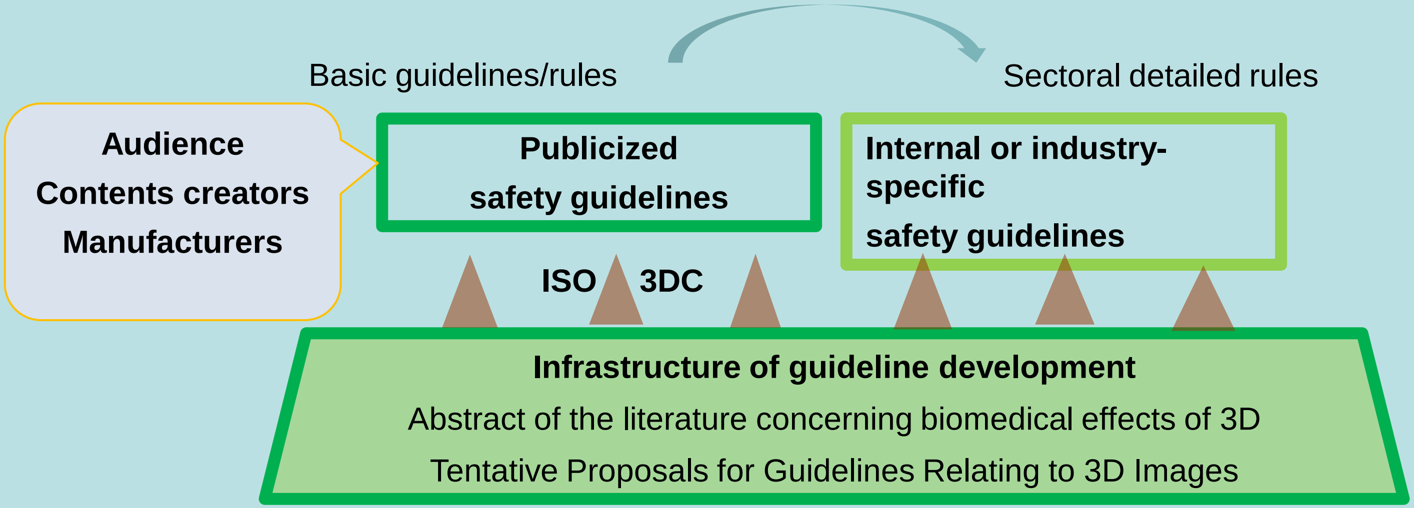
Therefore, as a part of a project to promote comfortable 3D by the Ministry of Economy, Trade and Industry which started on November 30, 2009, we conducted a bibliographical survey for the past 10 years and discussions with researchers and concerned parties in the business. As a result, we decided to conduct full-fledged revision of the guidelines.

Positioning of the 3DC Safety Guidelines

The 3DC Safety Guidelines are intended to be publicized for a healthy cultivation of the 3D industry.

The minimum required knowledge, policies and rules we would like all the people involved in the 3D industry (audience, contents creators, equipment manufacturers) to know are summarized into these guidelines.
To realize comfortable 3D, there are many more points to be considered.
Please refer to the information such as the abstract of the literature concerning biomedical effects of 3D (2010) and the Tentative Proposals for Guidelines Relating to 3D Images" (1999) by the Japan Electronics and Information Technology Industries Association (JEITA) for development of internal or industry-specific safety guidelines.

Positioning of safety guidelines



[Characteristics of the 3DC Safety Guidelines]

<u>Guidelines consist of items indicated with <GL-N> where N is a serial number. Background color is</u>

Contents: Expressed in a form such as ".... is advisable", ".... is recommended", ".... shall be avoided", etc.

Explanation: Causes, manner of operation and case examples are provided.

Basic knowledge which is not the part of guidelines but is important to realize human-friendly 3D and explanations to support understanding and implementation of guidelines are provided under <Note-N>.

<u>Where N is a serial number and background color is</u>

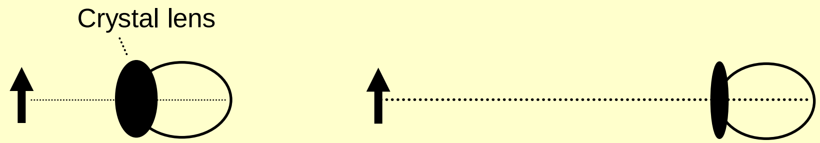
Items such as binocular disparity which are difficult to understand only by text are explained with illustrations.

<Note>Principle of stereopsis

We feel three dimensions and depth with cues described from (1) to (14) below:

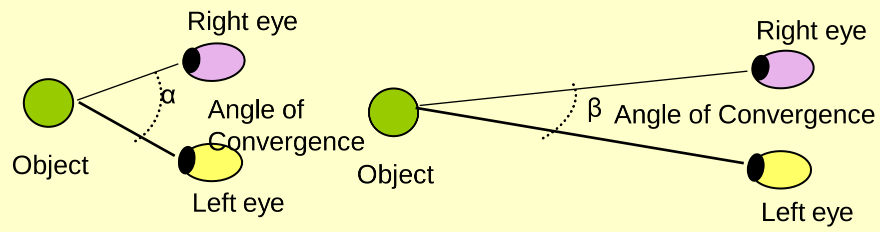
(1) Focal accommodation of crystal lens

Crystal lens become thicker when we see objects close to us.
Crystal lens become thinner when we see objects far from us.



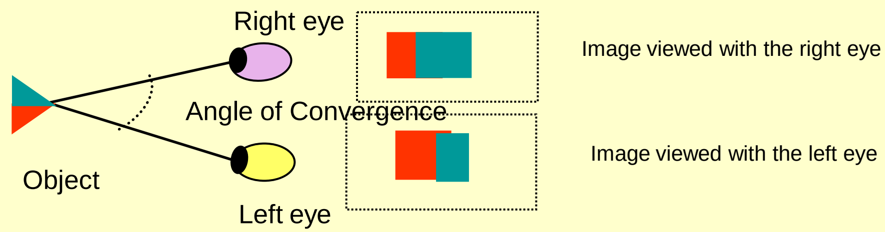
(2) Convergence of both eyes

Angle of convergence becomes larger when we see objects close to us.
$\alpha > \beta$
Angle of convergence becomes smaller when we see objects far from us.
$\alpha < \beta$



(3) Binocular disparity

The distance between the right and left eye is around 6 cm; therefore, their viewpoints are different which makes them recognize different images.



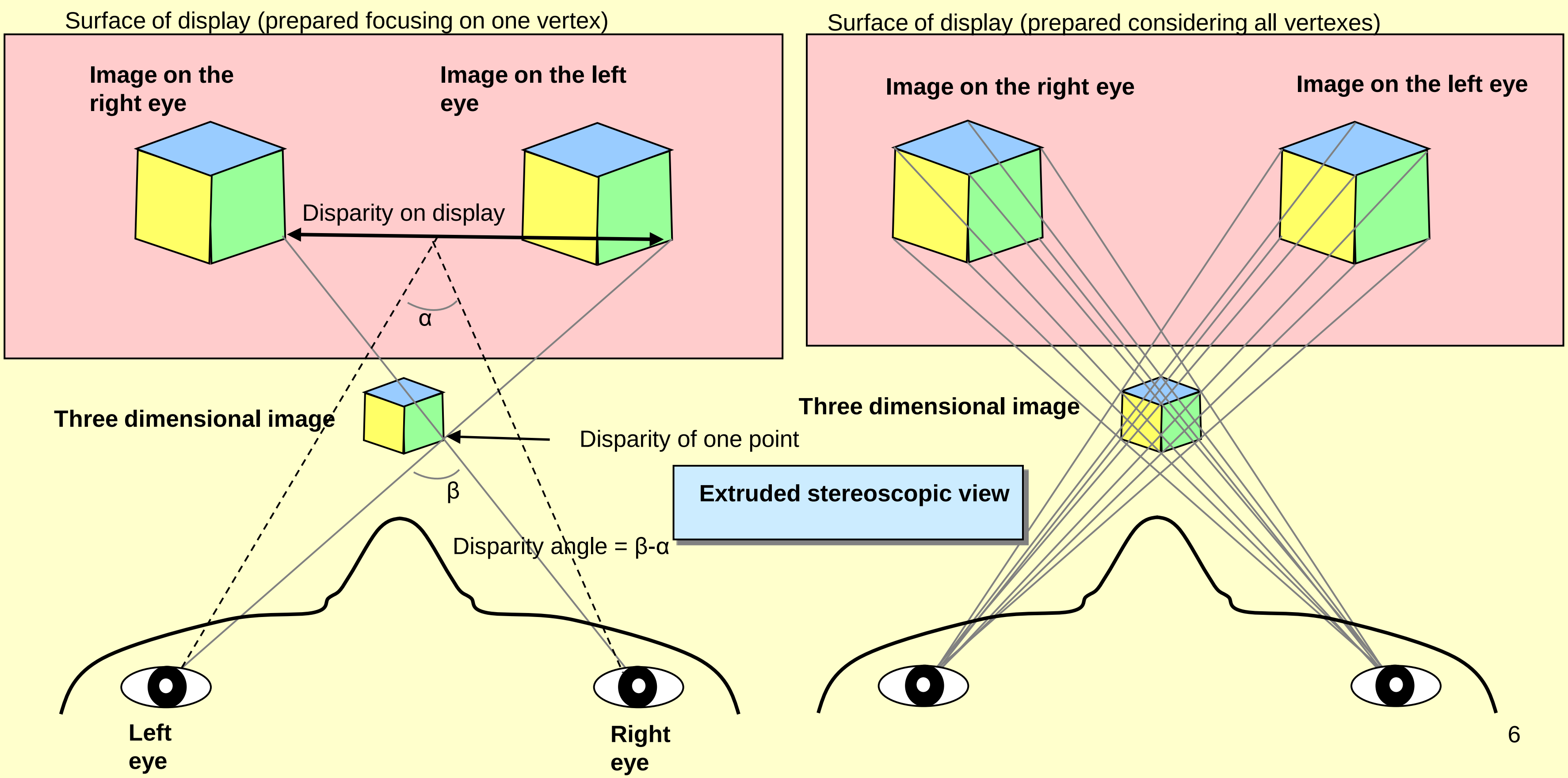
(4) Monocular movement parallax
When we see a landscape from a train window, the closer the object is to us, the faster the image we recognize moves.

(5) Size of objects	*(6) Height of objects*	*(7) Overlapping of objects*	*(8) Density of texture*	*(9) Shape*
(10) Lighting (shading)	*(11) Contrast*	*(12) Saturation*	*(13) Hue*	*(14) Definition*

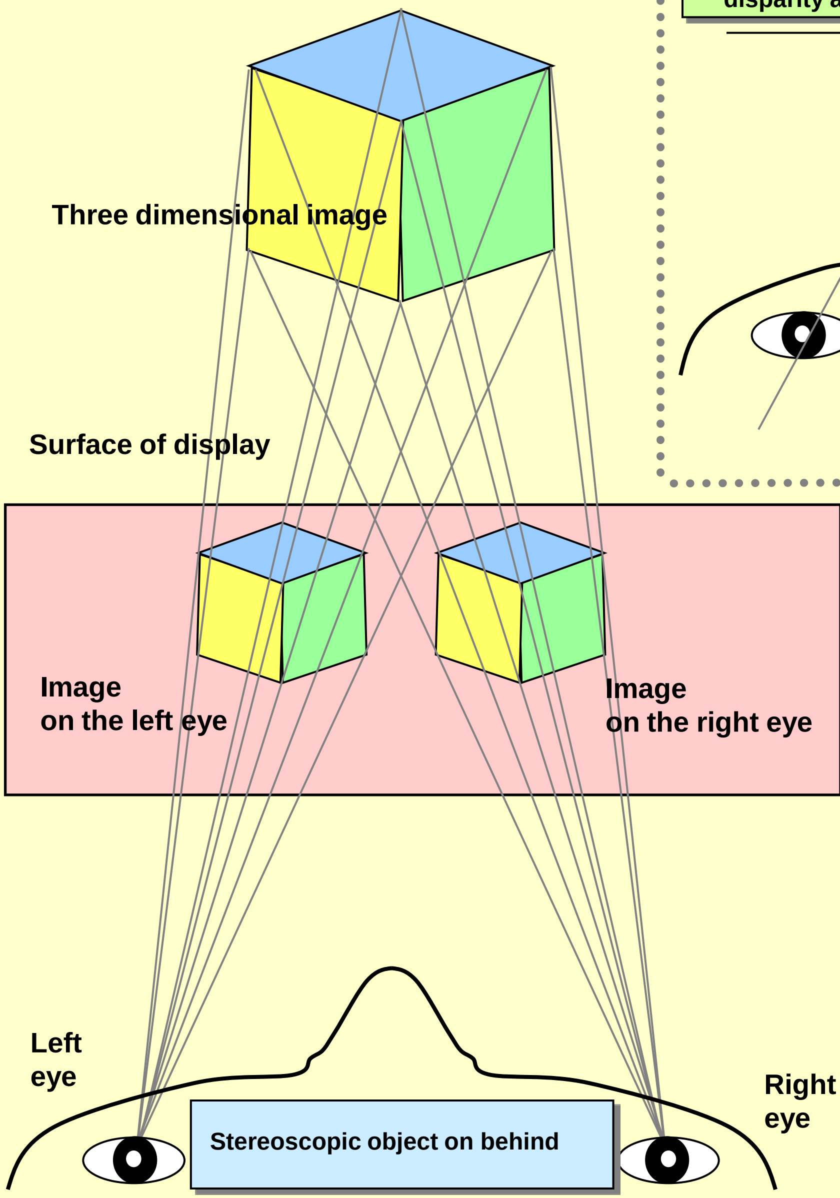
<Note> Mechanism of 3D displays based on binocular disparity principle

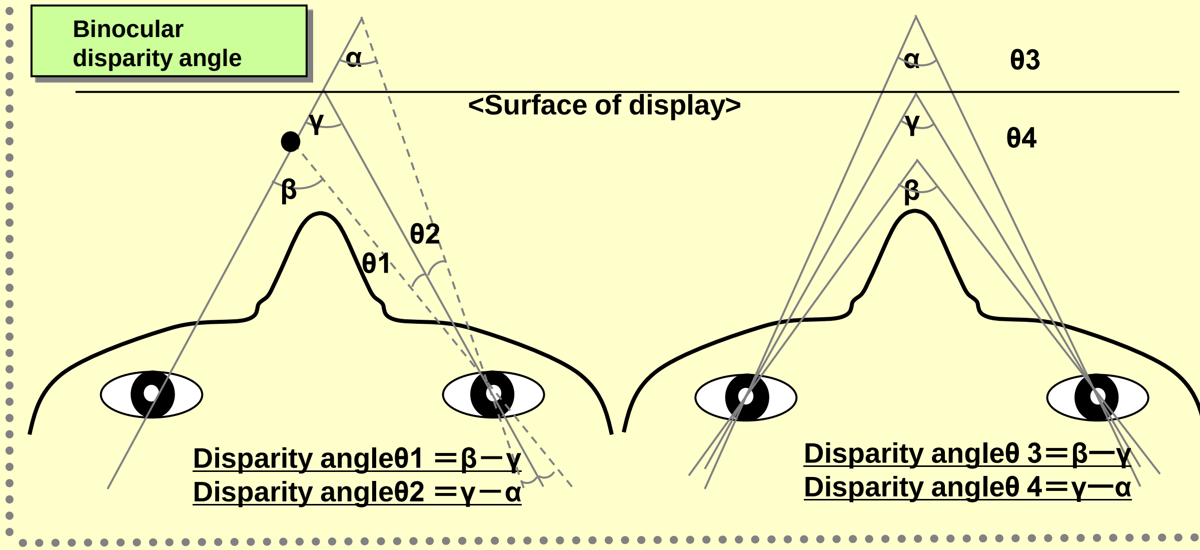
The distance between our right and left eye is around 5 - 7 cm. Therefore, images which are recognized with each eye differ due to differences of their viewpoints. The closer the distance to the subject is, the bigger the difference becomes and vice versa. Our brain recognizes three dimensions according to the difference.

Therefore, separately providing images with different viewpoints to the right eye and left eye makes us feel the depth. 3D displays utilize binocular disparity and provide different images on our right eye and left eye by using methods such as barriers. For example, if images for the right eye and left eye are allocated on the display based on this principle as in the illustration below, we can recognize a three dimensional box extruded from the surface of the display.



<Note> 3D display utilizing binocular disparity





If the images for the left eye and right eye are allocated on the surface of the display as in the figure on the left, we feel as if the object is located behind the display.
The difference between the angle of convergence (γ) when we look at only one point on the display and the angle of convergence when we look at the three-dimensional image recognized by binocular disparity (α, β) is called the disparity angle.

The distance between the corresponding point on the image for the right eye and left eye is called disparity on display.

3D displays covered by these guidelines

The power of binocular disparity is strong; this principle enables easy realization of stereopsis.

Most of the commercially available equipment which enables stereopsis is based on this principle.

In addition, a large number of study examples for comfortably enjoying stereoscopic images exist.

Therefore, these guidelines focus on 3D displays based on the binocular disparity principle.

3D TVs and 3D displays with image qualities which are the same or better than currently available 2D TVs are covered by these guidelines.

[About 3DC Safety Guidelines for Dissemination of Human-friendly 3D]

Contents of these guidelines

GL1 - 7 Guidelines which shall be provided to the audience

Confirmation of stereopsis, confirmation for prevention of reversed images, appropriate posture when viewing stereoscopic images, appropriate positions for viewing stereoscopic images, appropriate duration for viewing stereoscopic images, consideration for the younger generation and arousing the attention to the audience.

GL8 - 13 Guidelines for contents creators

Disparity limit in the divergent direction, the range of comfortable disparity (No. 1, No. 2,

No. 3, No. 4) binocular fusion limit, display size and disparity, shooting with cameras, synchronization of cameras

GL14 - 15 Guidelines for manufacturers

Recommended frequencies for crosstalk and time division display methods

Basic knowledge for utilizing guidelines is explained as "Note".

Guidelines which shall be provided to the audience

for comfortable viewing of stereoscopic images

Providing descriptions on instruction manuals, preliminary explanations during occasions such as events, and preliminary explanations by distributing information are advisable. Guidelines shall be provided to the people who are involved with the 3D industry.

<GL-1> Confirmation of stereopsis

<GL-2> Confirmation for prevention of reversed images

<GL-3> Appropriate posture when viewing stereoscopic images

<GL-4> Appropriate positions for viewing stereoscopic images

<GL-5> Appropriate duration for viewing stereoscopic images

<GL-6> Consideration for the younger generation

<GL - 7> Arousing the attention to the audience

<Note - 1>Personal differences concerning stereopsis,

subjective symptoms, measurement methods and causes of eye strain and discomfort

<GL - 1>Confirmation of stereopsis

When 3D (stereoscopic) images look doubled or if there is any difficulty in recognizing stereoscopic images, immediately stop viewing, and check and adjust the display equipment and software configuration. If images are still doubled or if there is any discomfort which leads to difficulty in experiencing stereopsis, the use of stereoscopic images should be stopped immediately.

Explanation

Equipment which uses binocular disparity enables recognition of stereoscopic images only when users can fuse two images in their brain from different viewpoints which are input from their right eye and left eye.

If adjustment of the system is inadequate (inconsistency in the left and right optical axes, differences in size, color and brightness or vertical misalignment of the left and right images, or mixture of light between images on the left eye and the right eye (=crosstalk) is too large), it is difficult for users to fuse two images. In such a case, they maybe recognized as a double image which may cause eye strain.

Instruction manuals of products should be carefully read for adequate settings and use.

Personal differences exist in recognition of stereopsis based on binocular disparity; sometimes the audience must get accustomed to recognizing stereoscopic images.

It is advisable to provide sufficient care when providing explanations when selling equipment, having thorough descriptions written in instruction manuals, providing preliminary explanations during occasions such as events, and distributing information with preliminary explanations because some people are not able to experience stereopsis.

<GL - 2> Confirmation for prevention of reversed images

Unexpectedly, users hardly recognize when images provided to the left eye and the right eye are reversed. However, left-right reversal causes eye strain and discomfort; therefore, it is advisable to prevent left-right reversal.

Explanation:

Theoretically, if images to be provided to the left eye and the right eye are reversed, reversion of convexo-concave must occur; however, the perception of depth of images is not only recognized through binocular disparity.

Therefore, reversal is not often recognized by the audience.

Sometimes, the audience is exposed to reversed images due to a misconfiguration of hardware, operational errors concerning software, inappropriate data format, and miscommunication when data is delivered.

Users often look at reversed images without knowing that they are reversed;

therefore, it is recommended that measures be taken to confirm if appropriate images are recognized by the left eyes and the right eyes of the audience when installing equipment.

During events concerning stereoscopic images, reversed images caused by mis-synchronization of liquid crystal shutter glasses or by provision of inappropriate information to those in charge of installation of equipment are sometimes recognized.

Sufficient consideration for this possibility is advisable.

Standardization to prevent reversed images in the entire industry is advisable.

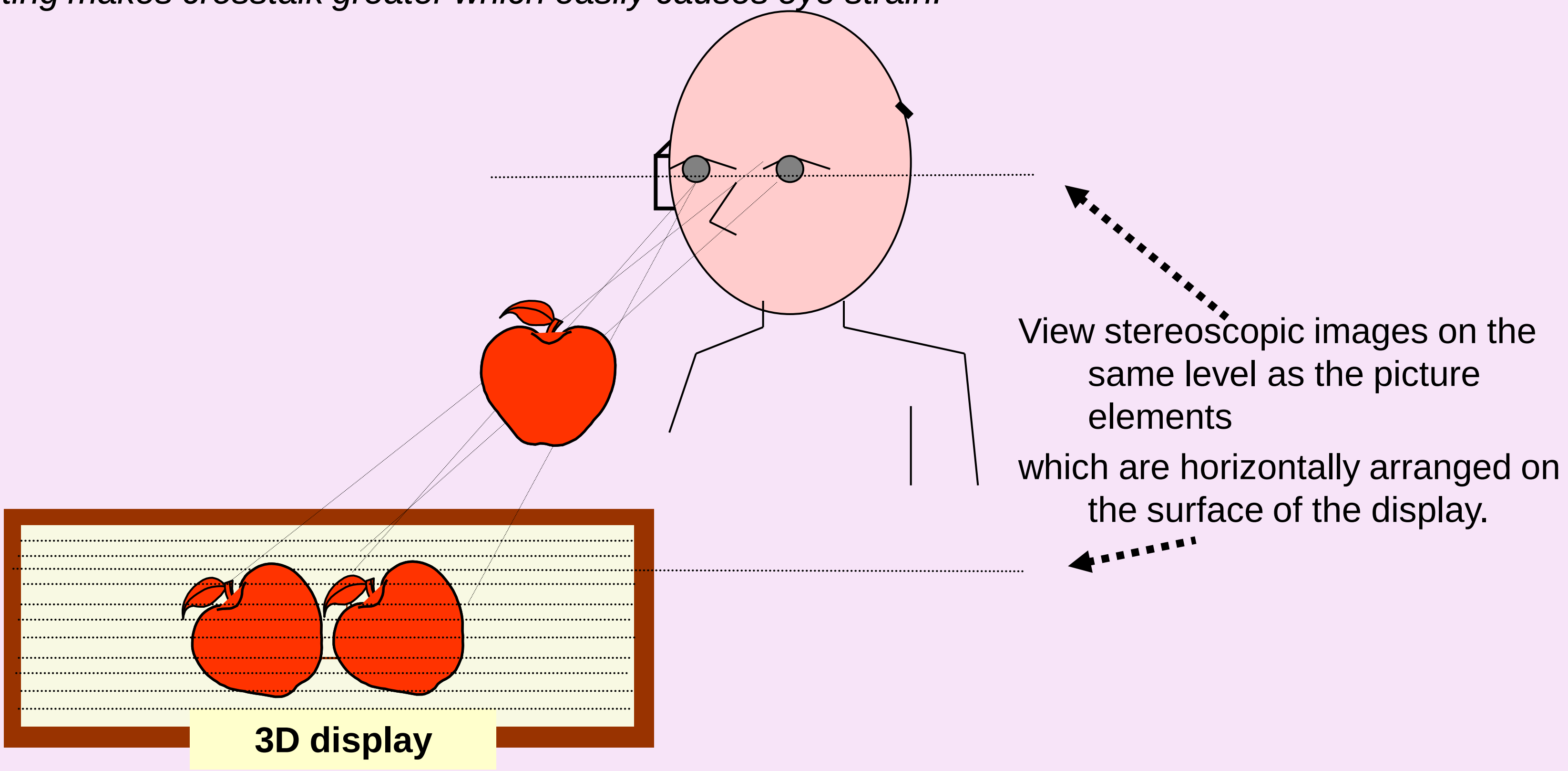
<GL-3> Appropriate posture when viewing stereoscopic images

Concerning images based on binocular disparity, it is advisable to view them in a posture where the surface of the display and both eyes are on the same level.

Explanation: If both eyes are on a slant to the surface of the display,

differences in upper and lower images recognized by the left eye and the right eye become larger which makes fusion of images difficult and causes eye strain. When viewing stereoscopic images by using glasses based on linear polarization,

slanting makes crosstalk greater which easily causes eye strain.



<GL - 4>Appropriate positions for viewing stereoscopic images

It is advisable to view stereoscopic images from an appropriate position.

Explanation

Usually, stereoscopic content is created assuming that the audience views it in the front of the display. In addition, high resolution TVs are manufactured assuming that viewers see the screen at the distance which is three times the height of the screen. Note that disparity angles become larger when content is viewed from positions closer than that, and they become smaller when content is viewed from farther than that.

If the disparity angle when images are viewed at the standard viewing distance (3 times the height of the screen (3H)) is 1 degree, by changing the distance of sight, the disparity angle will change as much as 3 degrees for 1H, 2 degrees for 1.5H, 1.5 degrees for 2H, 1 degree for 3H, 0.75 degrees for 4H, 0.6 degrees for 5H and 0.5 degrees for 6H.

Therefore, sufficient care must be taken for positioning of seats at sites of events and home theaters.

Also, attention is required for GL-5.

In addition, diagonally viewing a screen makes the trapezoidal distortion bigger. It makes formation of appropriate stereoscopic images difficult which may lead to fatigue or sickness.

<GL - 5>Appropriate duration for viewing stereoscopic images

Viewing 3D (stereoscopic) images shall be discontinued when any abnormal conditions are recognized such as fatigue or discomfort.

If fatigue or discomfort still exists after taking a break, it is advisable to stop viewing.

Subjective symptoms such as fatigue or discomfort shall be regarded as a warning from our body.

It is also important to confirm if stereoscopic images are being viewed under an appropriate configuration.

Adherence to VDT guidelines is recommended when handling stereoscopic images by operations using video display terminals (VDT).

Explanation

Since personal differences are significant in degrees of feeling eye strain and motion sickness which also relate to various factors, adherence to these guidelines is advisable in terms of duration of use.

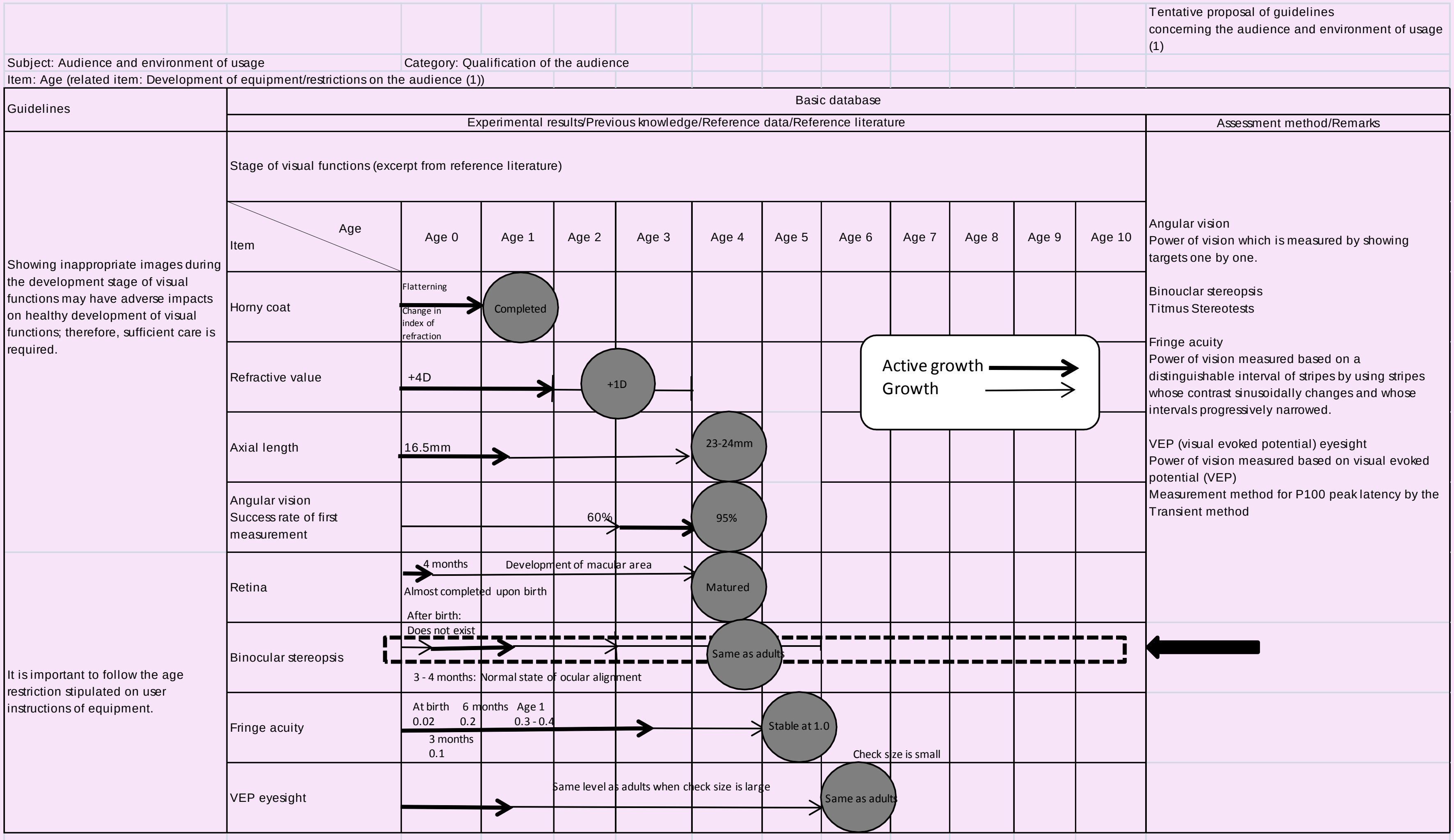
When having difficulty in achieving stereopsis or when feeling discomfort such as motion sickness, it is effective to temporarily look away from the screen.

It is advisable to make these guidelines provided to 3D users. For example, it is recommended to include these guidelines in instruction manuals of 3D related equipment and in explanations before showing content to the audience. It is advisable to show children stereoscopic images under accompaniment of adults because adherence to these guidelines is difficult for children who are not adequately able to tell others about their physical conditions.

Refer to VDT guidelines when handling stereoscopic images while operating VDTs. http://www.mhlw.go.jp/houdou/2002/04/h0405-4.htmlThese guidelines recommend that "Persons who are involved in operations by using VDTs shall not continue operations more than one hour; breaks of around 10 - 15 minutes shall be taken before another continuous operation starts and one or two short breaks shall be taken during one cycle of continuous operation."

<GL - 6> Consideration for the younger generation

If viewing of 3D content by children is required, it is advisable that adults accompany them, make a judgment if viewing is appropriate and limit the duration of viewing considering the impact on visual performance in their developmental stages (reference data is shown below).



Excerpt from the "Tentative Proposals for Guidelines Relating to 3D images" published by the Japan Electronics and Information Technology Industries Association in June 1999.

<GL - 7> Arousing attention during viewing

For achieving comfortable viewing of 3D, it is advisable that measures to be taken when feelings of fatigue and discomfort during viewing

are described as in the instruction manuals or known to the audience during the preliminary explanations to the participants of events.

Special attention is required when live images or live action shots are presented because they may have an unexpected sudden increase of disparity or violent motions.

Explanation:

(1) When viewers feel difficulty in achieving stereopsis or feel temporary fatigue or discomfort, ask them to remove their glasses and look away from the screen. Fatigue or discomfort may occur due to scenes with large disparity, drastic changes in disparity such as rapid movements or a rapid change in disparity.

The following descriptions and measures are applicable and effective to 2D images as well as to 3D images.

(2) When viewing video content with movements such as rotation, or horizontal or vertical oscillation, we may feel as if we are actually moving (visually induced self-motion sensation).

If such feelings are recognized as discomfort (motion sickness), look away from the screen.

(3) Motion sickness may be mitigated by viewing images in a well-lit room.

(4) If fatigue and discomfort still continue after taking a break, it is advisable to stop viewing stereoscopic images.

<Note - 1> Personal differences concerning stereopsis, subjective symptoms, measurement methods and causes of eye strain and discomfort

Note that personal differences exist in terms of stereopsis caused by binocular disparity; some feel difficulty in achieving stereopsis and some easily feel eye strain with stereopsis, but others do not feel fatigue even with strong disparity. Therefore, careful handling by adhering to guidelines is advisable when showing stereoscopic images to the general public.

Subjective symptoms, measurement methods and causes of eye strain and discomfort caused by stereopsis

(1) Subjective symptoms of eye strain and discomfort caused by stereopsis include the following:

Feeling fatigue in the eyes, feeling "heavy" in the eyes, seeing double images, feeling dry eyes, and feeling heavy in the head or headaches.

Stiffness in the shoulder, shoulder pain, back pain, sick feelings, dizziness, motion sickness, etc.

(2) Objective measurement methods (objective evaluation) concerning eye strain and discomfort include the following. However, there are no standardized methods and they are under research.

The following methods are used often.

Binocular fusion limit CFF, visual performance (adjustment function, convergence function), eyesight, evoked potential, and autonomic nervous system (pupils, cardiac electrogram, blood pressure)

(3) The following are possible causes of eye strain and discomfort:

Unnatural stereopsis, inappropriate configuration of disparity, discrepancies between adjustment and convergence, distortion of images, puppet theater effect, cardboard effect, distortion around frame, existence or non-existence of vertical disparity and discrepancy of movement disparity

Geometrical misalignment of left and right images (especially in the vertical direction), differences in optical characteristics and colors of left and right images

Glasses (red and blue glasses) for the anaglyph technique are used often because they can easily be made; however, they cause binocular rivalry because of differences in color which easily leads to fatigue.

Since stereoscopic images are not real images but a simulated experience based on stereopsis, a certain sense of discomfort cannot be avoided; however, with careful configuration of display equipment and content, comfortable viewing experiences can be provided.

Guidelines for content creators for comfortable viewing of stereoscopic images

<GL - 8>Disparity limit in the divergent direction

<GL - 9> The range of comfortable disparity (No. 1, No. 2 and No. 3)

<GL - 10>Binocular fusion limit

<GL - 11> Display size and disparity

<GL - 12> Shooting with cameras

<GL- 13> Synchronization of cameras

<Note - 2> Interpupillary distance (distance between eyes) of children

<Note - 3> Display size and disparity

<Note - 4> Adjustment of binocular disparity (No.1, No.2, No.3 and No.4)

<Note - 5> Relations between positions of three dimensional objects and images shot by left and right cameras (disparity)

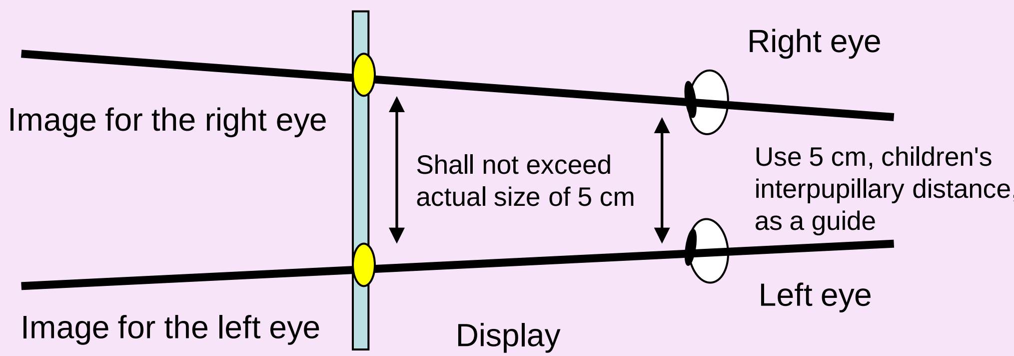
<Note - 6>Camera intervals and disparity

<Note - 7>Reference data to prevent motion sickness (No.1 and No.2)

<GL - 8>Disparity limit in the divergent direction
Concerning stereoscopic images shown in the retracted direction on the display, it is advisable to avoid disparity which exceeds the interpupillary distance (5 cm if children are considered) as much as possible especially for the images which attract attention by an audience.

Explanation: Our eyes do not open outward; therefore showing stereoscopic images with a large disparity causes eye strain because they do not fuse. This guideline is applicable regardless of distance of viewing. If disparity exceeds the limit, applying gradation effects during the post edit may mitigate the effects. However, it is difficult to apply such a technique for live events; therefore this guideline uses the expression "as much as possible" when considering such a situation. Sufficient care is required because such a phenomenon can frequently occur when presentation of stereoscopic images is made on a display which is larger than assumed.

Our eyes do not open outward; therefore showing stereoscopic images with large disparity causes eye strain because images do not fuse.



Reference data

Sizes of high definition TVs (16:9) and depth disparity limit on the display

Number of pixels corresponding to 5 cm of interpupillary distance

For definition of 1920 x 1080

Size	Pixels corresponding to 5 cm
200 inches	22 pixels
100	43
65	67
60	72
55	79
50	87
45	96
40	108

Note:
It is advisable that the information such as the display size is assumed when creating certain content or the amount of disparity used for calculation of the limit on the display size is communicated to the audience and hardware manufacturers.
If applicable, usage of corresponding tag areas of image formats is recommended.

<GL - 9> Range of comfortable disparity (No. 1)

Explanation: When we view stereoscopic images based on binocular disparity, we recognize these images on surfaces differently from the actual surface of the display. Our eyes try to focus on these stereoscopic images; however, images to be focused on actually exist on the surface of the display. This is referred to as the discrepancy between convergence and adjustment which are said to be one of the causes of eye strain and discomfort we feel when we view stereoscopic images.

Therefore, a range of depth (extruded or retracted objects) which enables "comfortable" viewing of stereoscopic images, or a comfortable disparity range exists. Excessive disparity interferes with achieving stereopsis, and causes double images which leads to eye strain and discomfort.

According to research and experimental rules, a disparity angle of 1 degree (60 minutes) or less can be used as a guide.

Personal differences are large for the binocular fusion limit; however, application of a moderate amount of around 2 degrees (120 minutes) is safe as a guide if the target is the general public. Acceptable ranges vary depending on various factors such as compositions and time variation; therefore, application of the amount which is more than the above-mentioned guide cannot be denied.

It is advisable to avoid rapid temporal or spatial changes in the disparity angle (1 degree or more) because it causes eye strain.

In academic papers, degrees or minutes are used as units to indicate differences in angles of convergence when referring to comfortable ranges and binocular fusion limits. However, it is difficult to achieve intuitive understanding with these units. On the next page, they are shown as rates (%) between the number of pixels on the display for high definition TVs (16:9) corresponding to the disparity and the width of the display. When assuming that content is viewed from the standard viewing distance of 3H (three times the height of the display (H)) for high definition TVs, using the corresponding number of pixels as a unit is more convenient for content creation.

Reference literature on disparity

1) M.Wopking: "Viewing comfort with stereoscopic pictures", Journal of the SID, 3, 3, pp.101-103 (1995)

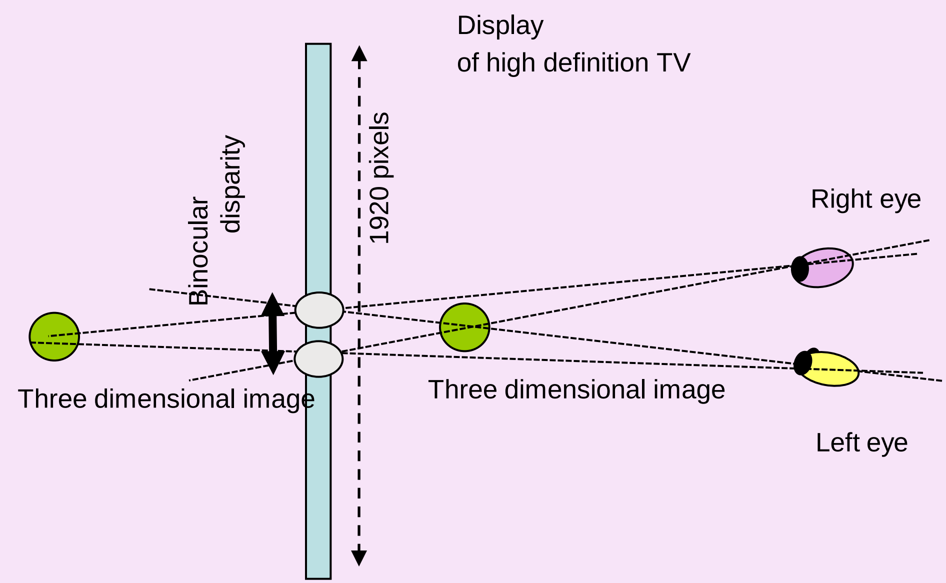
2) K.N. Ogle: "On the limits of stereoscopic vision", J. of experimental psychology, vol.44, 253-259 (1952)

3) "Basics of three dimensional images", supervised by Takehiro Izumi and edited by the NHK Science & Technology Research Institute (1995)

4) Sumio Yano: Size of Disparity for Binocular Fusion - A Study on Stimulus Target Properties, the transactions of the Institute of Electronics, Information and Communication EngineersJ75-d-2,10,pp1720-1728(1991)

5) Shojiro Nagata: "Fusional Characteristics of Binocular Parallax as a Function of Viewing Angle and Viewing Distance of Stereoscopic Picture", on the journal of the Institute of Television Engineer, 43, 3 , pp.276-281 (1989)

6) Shojiro Nagata: The conditions which have impacts on binocular fusion functions, a technical report by the Institute of Electronics, Information and Communication Engineers, Reference No. MBE91-116 (1991)



<GL - 9> Range of comfortable disparity (No. 2)

Explanation

The ranges of comfortable disparity assuming high definition TVs are shown below.

They are prepared assuming that the interpupillary distance is 6.5 cm and content is viewed from the standard viewing distance (three times the height of the screen of TVs). These figures are convenient, because by assuming these conditions, material impacts by the size of TVs and the interpupillary distance can be avoided.

When horizontal number of pixels is 1920

Disparity	Number of Pixels	Ratio against Display Width
0.7 degrees (40 minutes)	38 pixels	1.9%
1.0 degree (60 minutes)	57 pixels	2.9 %
1.5 degrees (90 minutes)	85 pixels	4.4%
2.0 degrees (120 minutes)	113 pixels	5.9 %

Comfortable range

It is said that recent 3D movies from Hollywood have been produced at around 2% of the extrusion or retraction against the width of the screen to mitigate fatigue and to achieve eye-friendliness when they are viewed for hours. Partially, images with more extrusion are used; however in such a case, it is advisable to apply a gradual increase of disparity to avoid rapid temporal changes in disparity. In addition, as a reference, there is a research result indicating that eye-friendly images can be created by limiting the range of depth on the same screen within a degree.

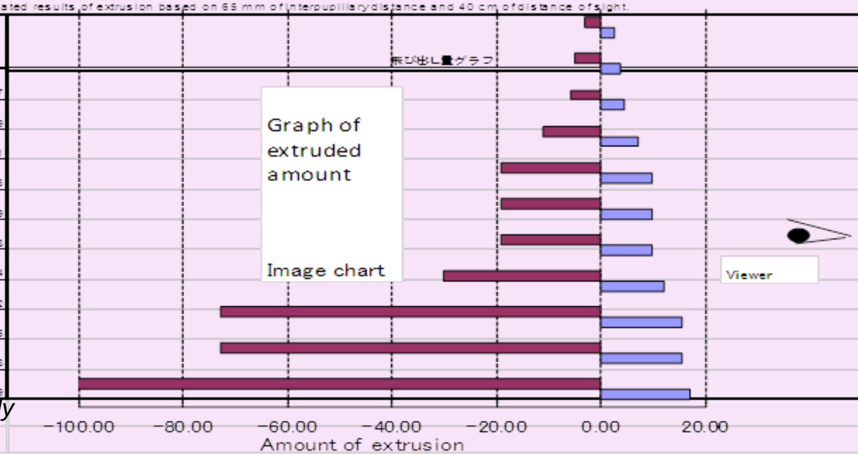
However, much care is required for disparity in the retracting direction (refer to GL - 8).

<GL - 9> Range of comfortable disparity (No. 3)

Explanation: When we view stereoscopic images based on binocular disparity, we recognize these images on surfaces differently from the actual surface of the display. Our eyes try to focus on these stereoscopic images; however, images to be focused on actually exist on the surface of the display. This is referred to as the discrepancy between convergence and adjustment which are said to be one of the causes of eye strain and discomfort we feel when we view stereoscopic images.
Therefore, a range of depth (extruded or retracted objects) which enables "comfortable" viewing of stereoscopic images, or a comfortable disparity range exists. Excessive disparity interferes with achieving stereopsis, and causes double images which leads to eye strain and discomfort.
For "comfortable" viewing of stereoscopic images, major images of objects shall be allocated within the range of depth (extruded or retracted objects) which means the disparity range. Excessive disparity causes double images which leads to eye strain. It is important to keep disparity within the range which allows binocular fusion. 60 minutes (1 degree) is a guide for the range of comfortable viewing. The following is reference data assuming images are viewed on PCs or mobile equipment. Data for binocular fusion limits were gathered from the documents mentioned in GL - 9 (No.1). The range of comfortable stereopsis greatly depends on measurement conditions; however, it is limited.

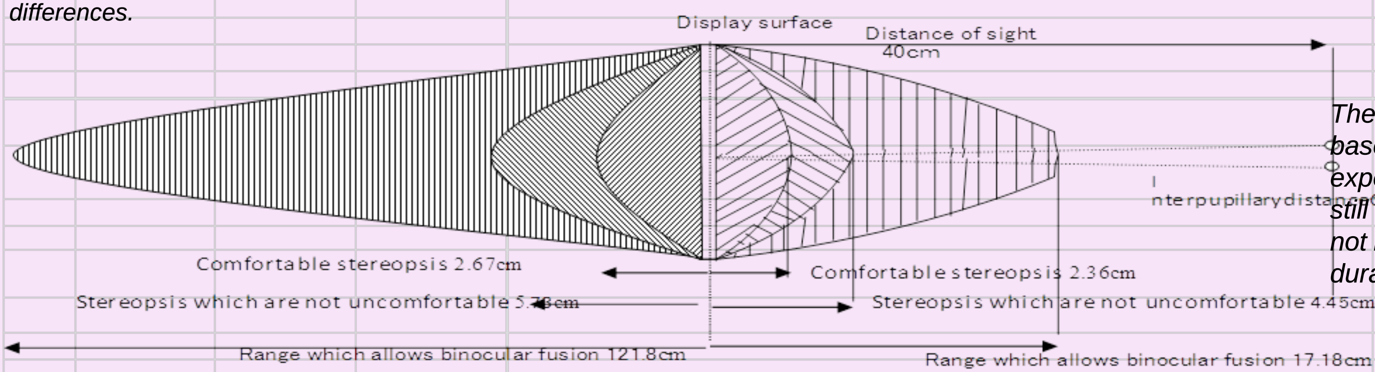
Calculated results of extrusion based on 65 mm of interpupillary distance and 40 cm of distance of sight.

Range which allows binocular fusion Disparity	Distance of extrusion (cm)	Distance of retraction (cm)	Measured value (measurement method)
35min	2.36	2.67	Comfortable stereopsis
40min	2.67	3.09	Clear-cut stereopsis: Subjective assessment
60min	3.88	4.81	Range which allows binocular fusion
70min	4.45	5.73	Boundary where discomfort is felt
80min	5.01	6.69	Clear-cut stereopsis: Subjective assessment
1.5 degrees	5.55	7.68	Range which allows binocular fusion
2 degrees	7.07	10.94	Range which allows binocular fusion
3 degrees	9.75	19.02	Range which allows binocular fusion
4 degrees	12.02	30.15	Range which allows binocular fusion
6 degrees	15.68	72.68	Range which allows binocular fusion
7 degrees	17.18	121.79	Range which allows binocular fusion



The range which allows binocular fusion greatly depends on conditions of experiments.

In addition, there are significant personal differences.



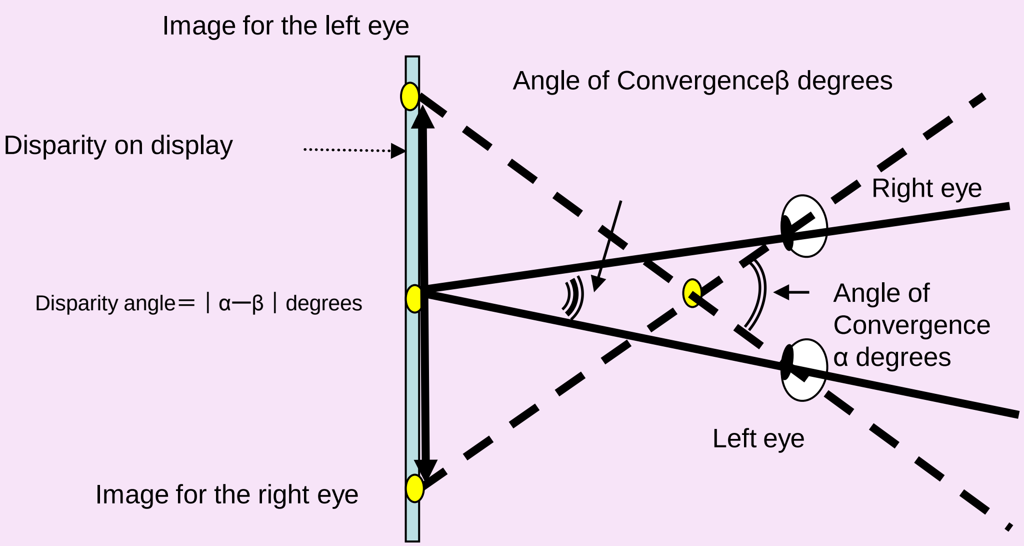
The above data is based on experiments using still images which do not limit a short duration of extrusions.

<GL - 10>Binocular fusion limit

Heavy usage of extruded stereoscopic images beyond the comfortable range of disparity and presentations for a long period shall be avoided; however, it is said that avoiding drastic time variations of disparity and using a gradual increase of disparity may mitigate the occurrence of fatigue and double images to a certain degree.

Explanation

It is said that stereoscopic images with large extrusions may cause eye fatigue because the inconsistency between adjustment and convergence will be significant. Since personal differences are large in terms of binocular fusion limit, the use of stereoscopic images with large extrusions shall be kept to a minimum by necessity since the assumed audience is the general public. The impact of stereoscopic images with large extrusions is one of the appeals of 3D; however, rapid changes in disparity cause eye fatigue and recognition of double images. Therefore, time variations shall be considered and a gradual increase of disparity is advisable so the eyes of the audience can handle changes of disparity. Please note that this guideline does not limit the use of short durations of extrusions which give a strong impact. Binocular fusion to recognize stereoscopic images in the extruded direction requires us to move our eyes to the direction toward our noses. There are personal differences; however, the binocular fusion limit in the direction may become larger when we force ourselves to move our eyes more.



The binocular fusion limit greatly depends on conditions of experiments. In addition, it is known that there are significant personal differences.

It is also reported that the larger the viewing angle becomes, the larger the binocular fusion limit becomes too.

Please refer to the following reference concerning the statistical data about binocular fusion limits and differences depending on the conditions of experiments.

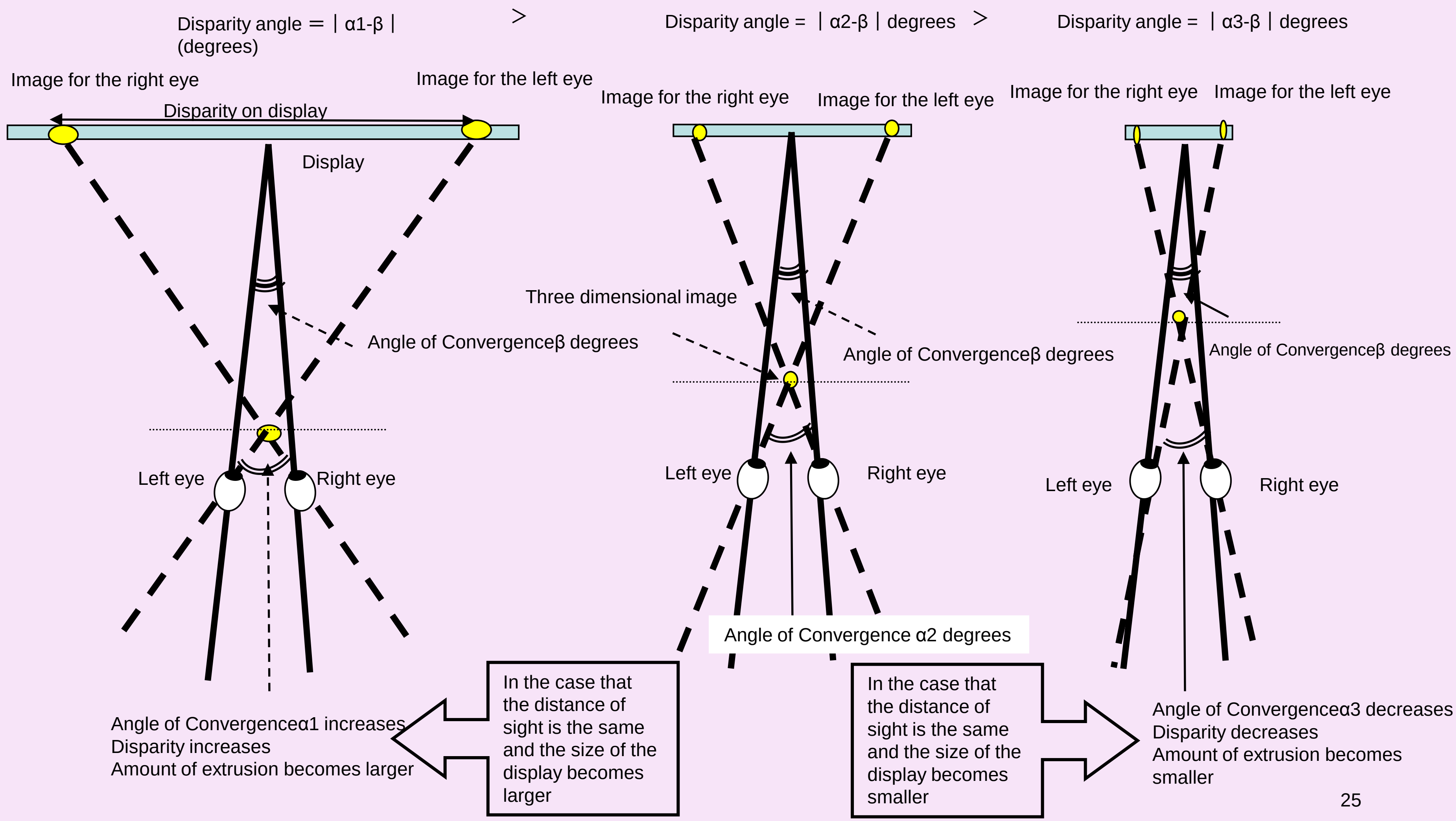
*(1) Shojiro Nagata: Distributions of "Vergence Fusional Stereoscopic Limit (VFSL)" of Disparity in a Stereoscopic Display*Transactions of the Virtual Reality Society of Japan 7(2), 239-246, 2002-06-30

(2) JEITA: "Tentative Proposals for Guidelines Relating to 3D Images" P94, 1999

<GL - 11>Display size and disparity

For creation of 3D content, it is advisable that the amount of disparity on a display is configured considering the binocular fusion limit which varies depending on the size of displays to be used for showing 3D images, and the distance of sight when 3D images are viewed.

Explanation: The amount of extrusion we feel from stereoscopic images shown on a display depends on the distance between the image for the left eye and that for the right eye. Assuming that the distance of sight is the same, the larger the display size becomes, the larger the amount of extrusion becomes, too. Therefore, the size of displays shall be carefully considered because the amount of extrusion may exceed the binocular fusion limit. The presentations on displays which are smaller than assumed will not cause problems because it makes disparity smaller than originally assumed. Refer to the Note for GL - 8.



<GL - 12> Shooting with cameras

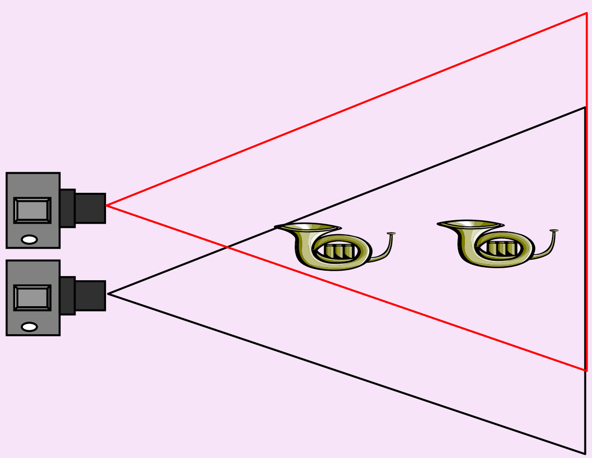
If two cameras are used for shooting images for the left eye and those for the right eye, these two cameras shall have similar characteristics as much as possible. In addition, inconsistency in the left and right optical axes and differences in the size of the left and right images shall be avoided including images which are shot with zooming and focusing operations.

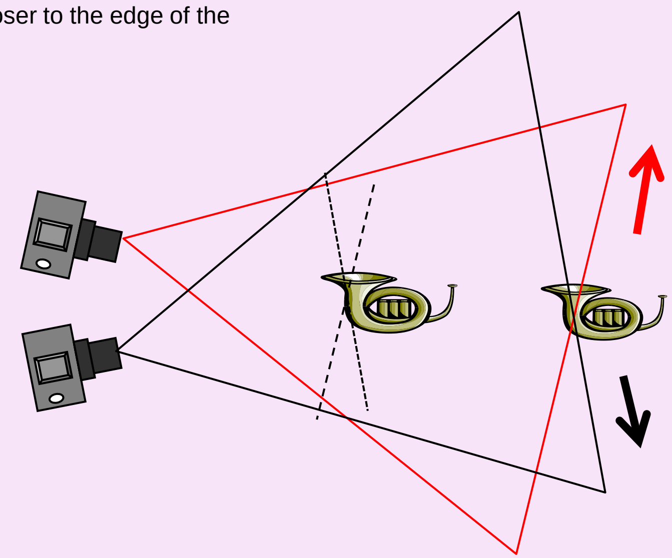
Explanation: Commercially available cameras for professional use may not cause such a problem; however, sometimes there is a need for handy shooting of stereoscopic images with cameras other than those types of cameras. In such a case, these two cameras shall have similar characteristics as much as possible. In addition, differences other than disparity concerning the images shot by these cameras (such as misalignment in the vertical direction, differences in sizes, timing of rotations, optical characteristics or colors of left and right images) shall be as little as possible. In addition, it should be noted that our eyes are sensitive to the misalignment of left and right images in the vertical direction; therefore, slight misalignment causes eye fatigue. In that sense, optical axes of left and right images in the vertical direction shall be adjusted to make them as parallel to each other as possible. A small misalignment can be adjusted later during the post-processing stage; however, it is advisable that the original configuration be made as precise as possible.

There are two types of configurations of cameras when they are used for shooting stereoscopic images; they are the parallel technique and the technique which simulates the convergence of eyes with cameras. When the technique which simulates the convergence of eyes is used, the disparity of the objects which are shown rearward on a display may become too large; therefore this technique shall be carefully used.

With the parallel technique, the further the object located in the center of two cameras is shown, the closer the object is shown to the center of the screen.
With this technique, disparity of the image shown in infinity will be the same as the distance between two cameras.

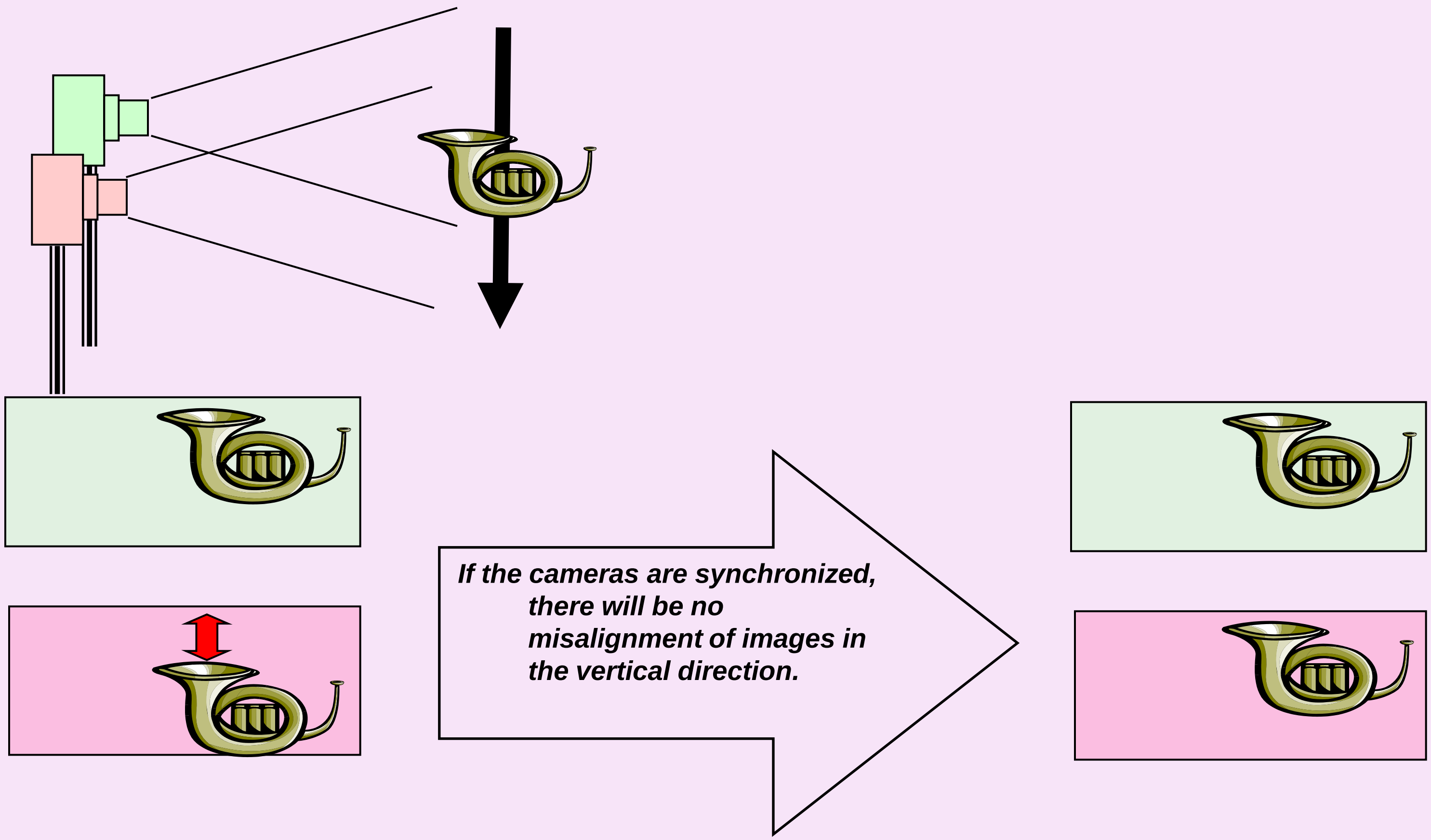
In the images which are shot by the technique which simulates the convergence of eyes,
objects which are shown further away are shifted closer to the edge of the screen which makes the disparity too large.





<GL - 13> Synchronization of cameras
When shooting 3D animation with multiple cameras, synchronization of cameras is required.

Explanation: Our eyes are very sensitive to the misalignment of left and right images in the vertical direction; therefore, a slight misalignment causes eye fatigue. When a moving subject is being shot, if the timing of shooting differs from the left camera and right camera, a vertical misalignment will occur between the left and right images. Even in the case that an object which is moving in the horizontal direction is shot, differences in timing of shooting may cause errors in disparity or alteration in the shape of the subject shot in the image which prevents fusion of images and causes fatigue.

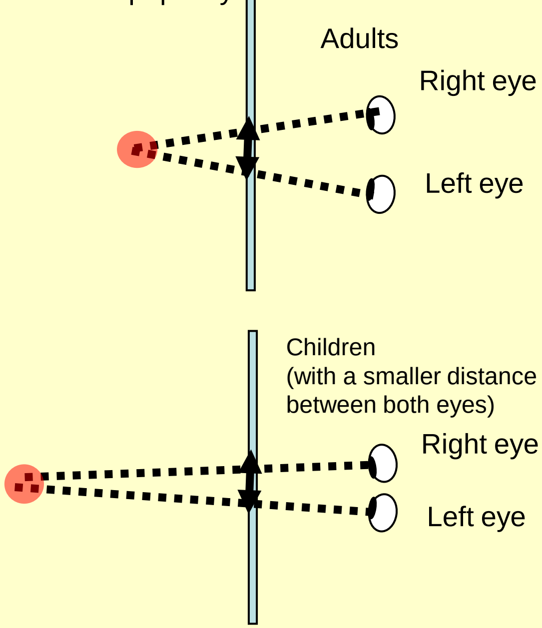


<u><Note - 2>>Interpupillary distance (distance between eyes) of children</u>

Concerning the stereoscopic images shown in the retracted direction on a display, creating disparity which exceeds the interpupillary distance shall be avoided as much as possible. This is because our eyes do not open outward.

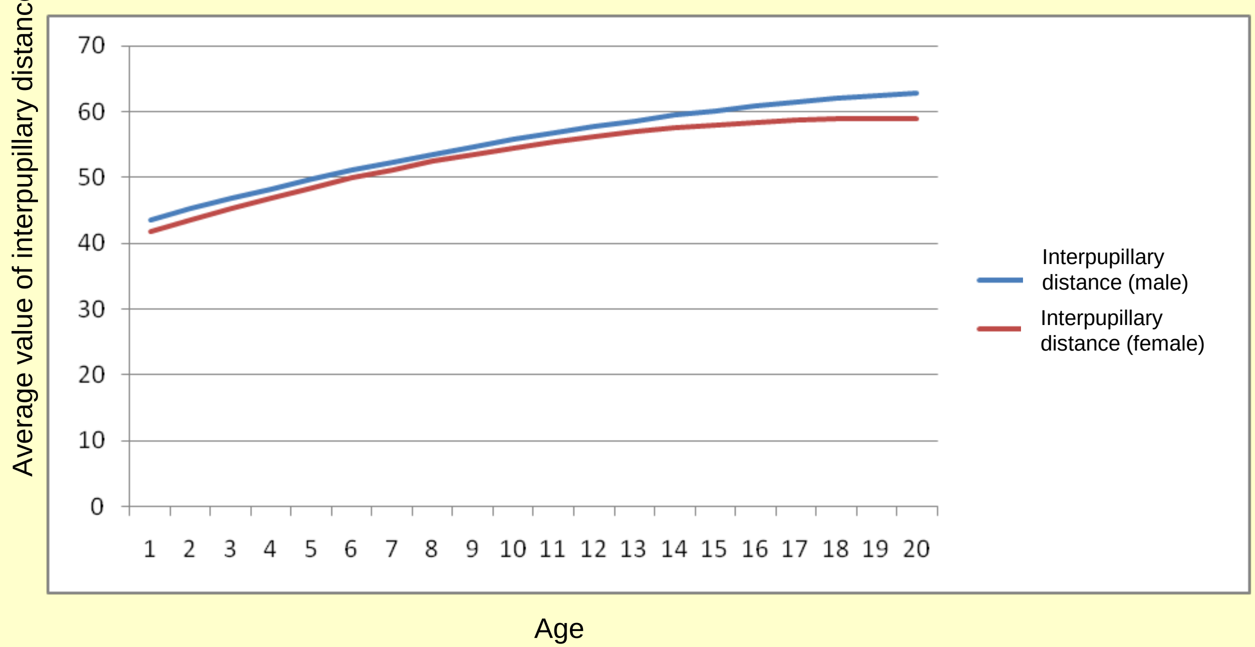
The sense of extrusion and depth of stereoscopic images can be controlled by adjusting disparity; however, it should be noted that people (children) with a smaller interpupillary distance (distance between the left eye and right eye) feel stereoscopic effects stronger than others even if the disparity is the same.

It should be noted that children feel the sense of stereoscopic view stronger because their interpupillary distance is smaller.



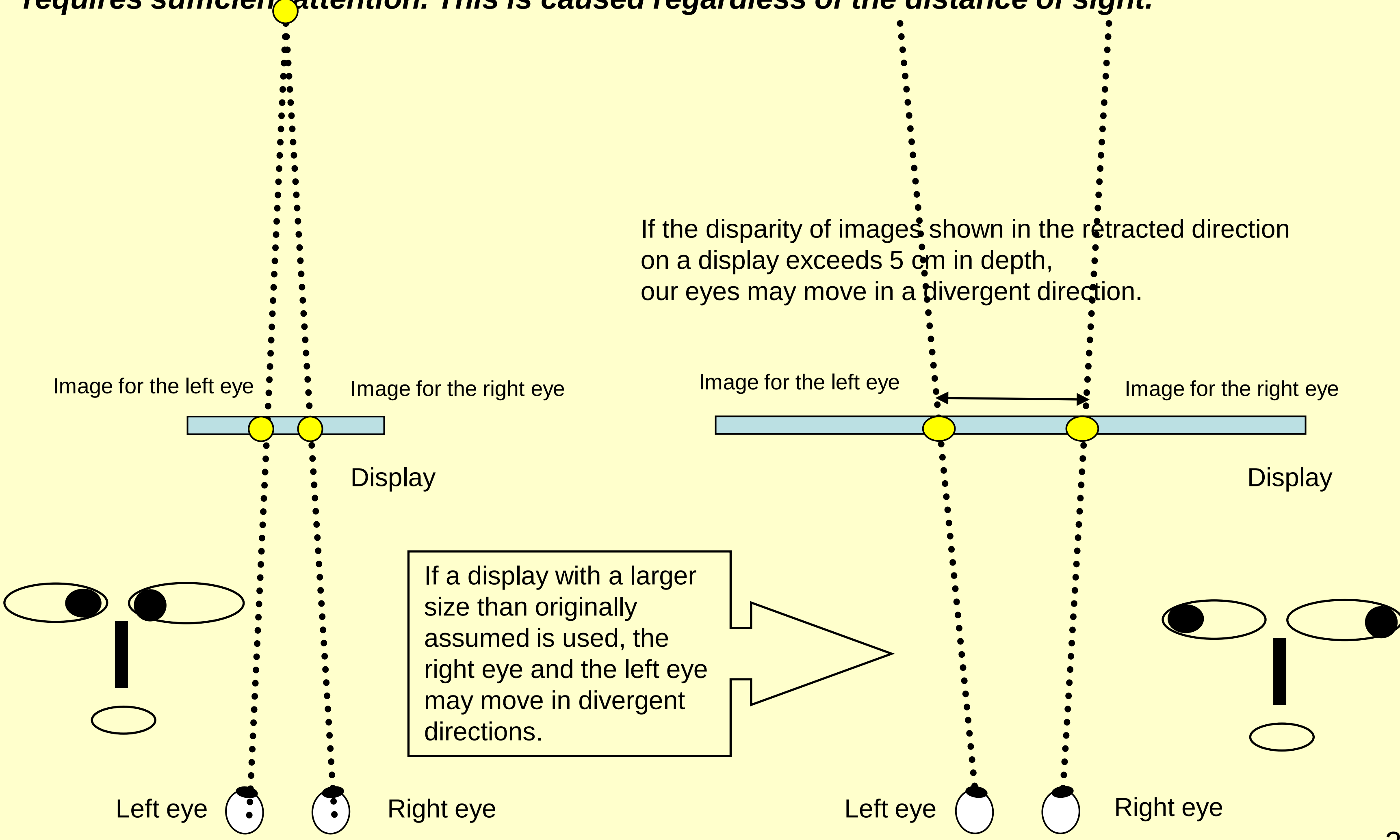
Basic data concerning the interpupillary distance (data from a research of 1311 children between one month to 19 years of age)
Colleen MacLachlan and Howard C. Howland; "Normal values and standard deviations for pupil diameter and interpupillary distance in subjects aged 1 month to 19 years", Ophthal. Physiol. Opt. 2002 22: 175–182

The interpupillary distance is around 5 cm for children who are 6 years of age. Considering the safety of the audience, this value is used as a representative value for children in these guidelines.



<Note - 3> Display size and disparity

When stereoscopic images are shown in the retracted direction from the surface of the display, if images are shown on a display with a larger size than originally assumed, disparity may exceed the limit of 5 cm. This may cause the right eye and left eye moving in the divergent directions which requires sufficient attention. This is caused regardless of the distance of sight.



<Note - 4>Adjustment of binocular disparity (No.1)

Making disparity larger makes the amount of extrusion and retraction of stereoscopic images larger which gives a greater impact on users. Actually, however, since there is a binocular fusion limit. if we make the disparity larger than a certain range, images recognized with our right eye and left eye will not fuse which causes double images. In such a case, stereopsis will not be achieved.

Creators of stereoscopic images tend to make disparity larger to render a sense of surprise; however, it is advisable to avoid presentation of images with larger disparity for a long period.

In addition, concerning the stereoscopic images shown in the retracted direction on a display, creating disparity which exceeds the interpupillary distance shall be avoided as much as possible. This is because our eyes do not open outward.

Binocular disparity shall be configured assuming the maximum size of displays which may be used to show stereoscopic images.

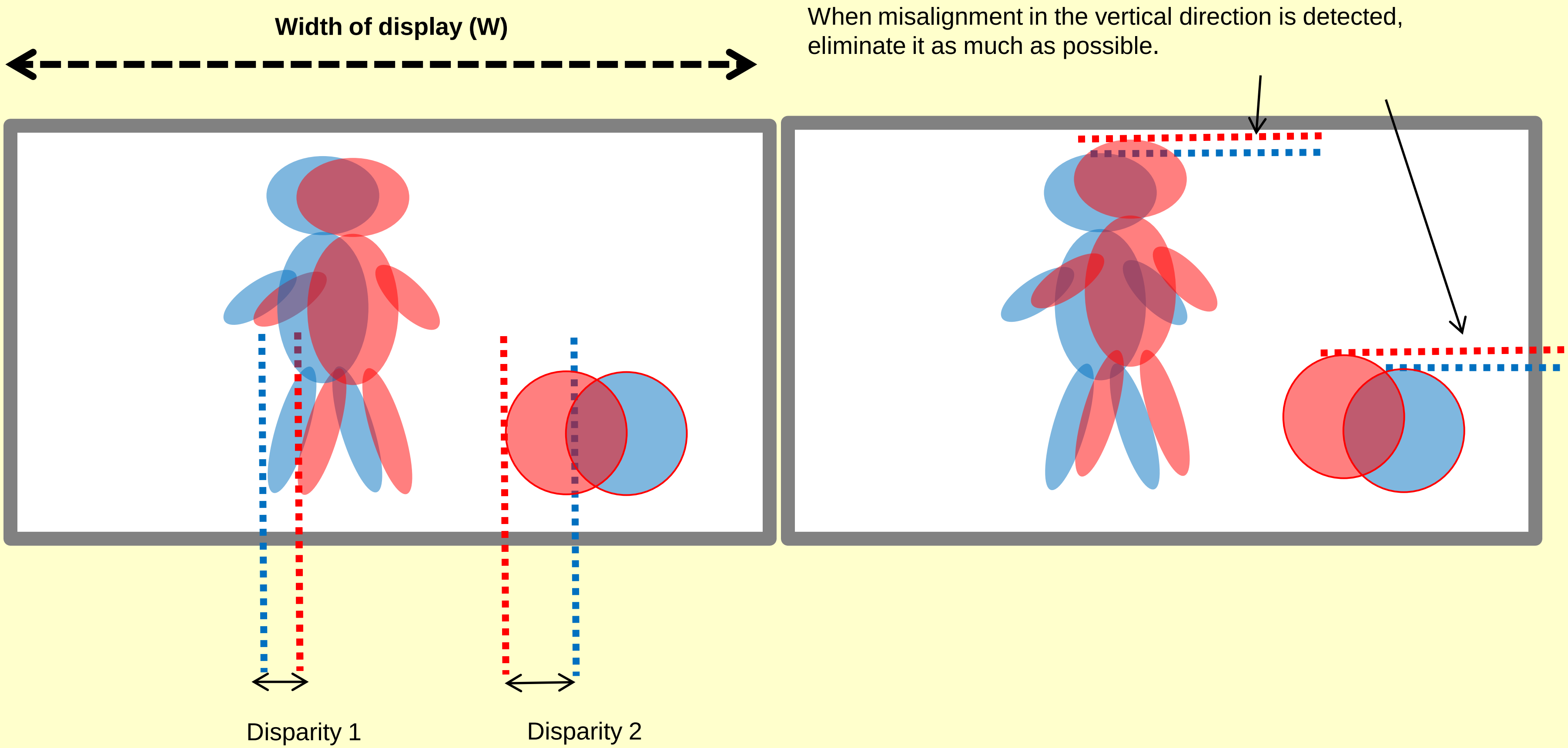
Actually, some people are good at achieving stereopsis based on binocular disparity, but others are bad at it or sometimes cannot achieve stereopsis.

Some people can view stereoscopic images for a long period without feeling any fatigue, and some people can easily be accustomed to viewing them; however, others will feel fatigue in only a short duration. The larger the disparity becomes, the larger this tendency becomes.

It is said that the disparity range which allows fusion of images will change when the person gets used to feeling stereopsis; therefore, having stereoscopic images viewed by people other than the creators of the images is effective to determine the allowable range for the general public.

<Note - 4> Adjustment of binocular disparity (No.2)
Concerning the 3D TVs with glasses, we can see overlapped images on a display when we see them without glasses; therefore it is convenient to check the scale of disparity on the display.

The scale of disparity can be judged based on a figure calculated by "Disparity/Width of display x 100%".
In the case of high definition TVs, it can be judged by the number of pixels.



Calculation of disparity on a display (S) in the case of stereoscopic images which are shown in the extruded direction

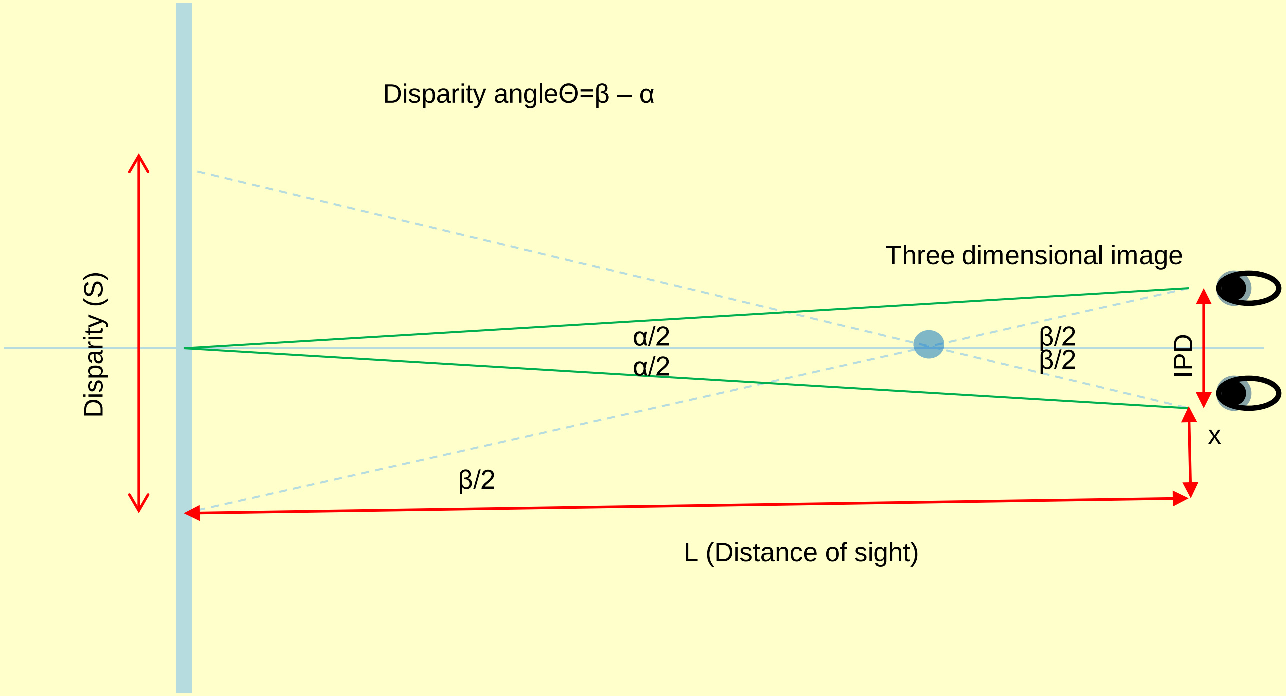
S= IPD+2*x
=2*(IPD + x)-IPD
=2*L*tan(β/2)-IPD
=2*L*(tan(β/2)- tan(α/2))
=2*L*(1+tan(β/2)*tan(α/2))*tan(θ/2)
≒2*L*tan(θ/2) (Since the interpupillary distance is usually small, using tan(β/2)*tan(α/2) ≪1)
as the disparity does not make significant discrepancy.)

α	Angle of convergence toward the center of the display
β	Angle of convergence against the stereoscopic image
θ	Disparity angle
IPD	Interpupillary distance
L	Distance of sight

IPD + x = L*tan(β/2)

β= α + Θ

IPD=2*L*tan(α/2)



<Note - 4> Adjustment of binocular disparity (No.4)

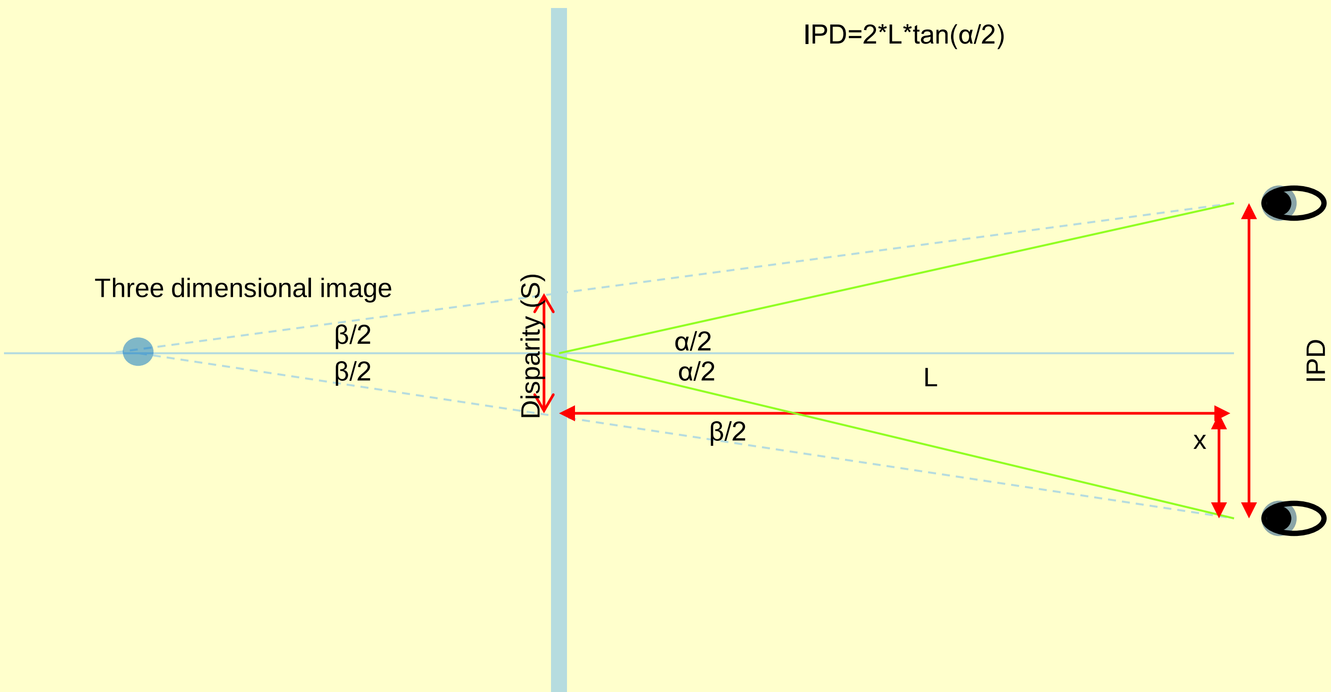
Calculation of disparity on a display in the case of stereoscopic images which are shown in the retracted direction.
(To make it easier to understand the illustration, the interpupillary distance is enlarged compared to the previous page.)

Disparity on display
$= IPD - 2*x$
$= IPD - 2*L*\tan(\beta/2)$
$=2*L*(\tan(\alpha/2) - \tan(\beta/2))$
$\fallingdotseq 2*L*\tan(\theta/2)$
Using the above as the disparity does not make a significant discrepancy.

$x = L*\tan(\beta/2)$

$\beta = \alpha - \theta$

Disparity angle $\theta = \alpha - \beta$



<Note - 5>Relations between positions of three dimensional objects and images shot by left and right cameras (disparity)

There are cases where two cameras are used for shooting stereoscopic images. By setting cameras used for shooting images for the left eye and the right eye with a certain interval as in the illustration below, images described in Illustration B can be shot. By overlapping parts which are common to images for the left eye and the right eye, we can see the disagreement in images in the horizontal direction. This is one type of binocular disparity.

Illustration A

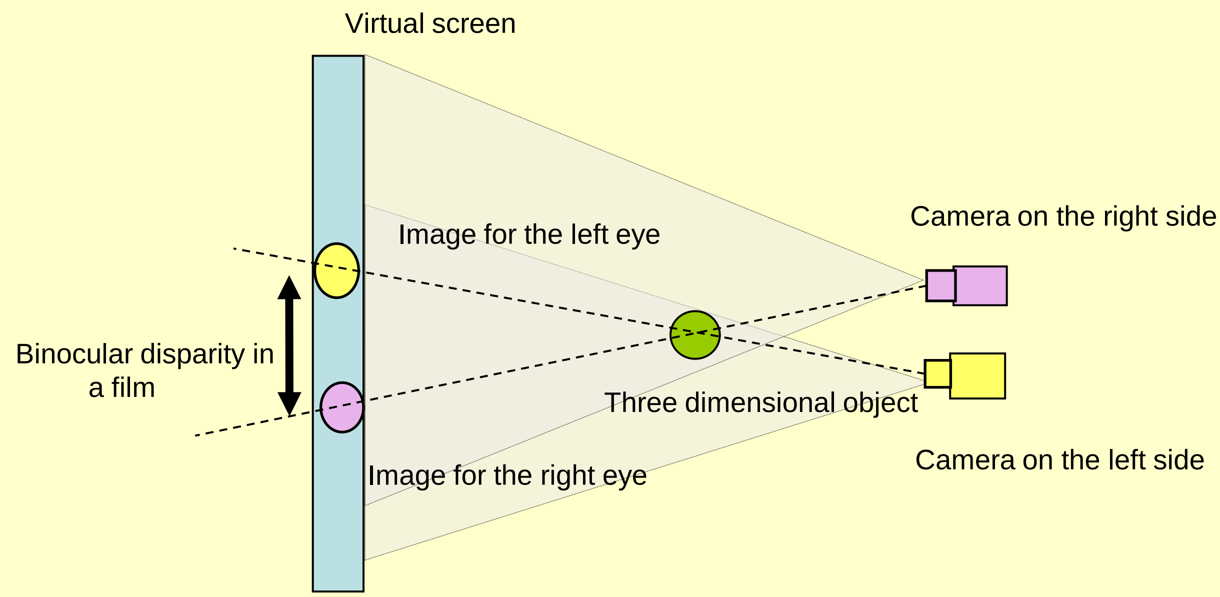
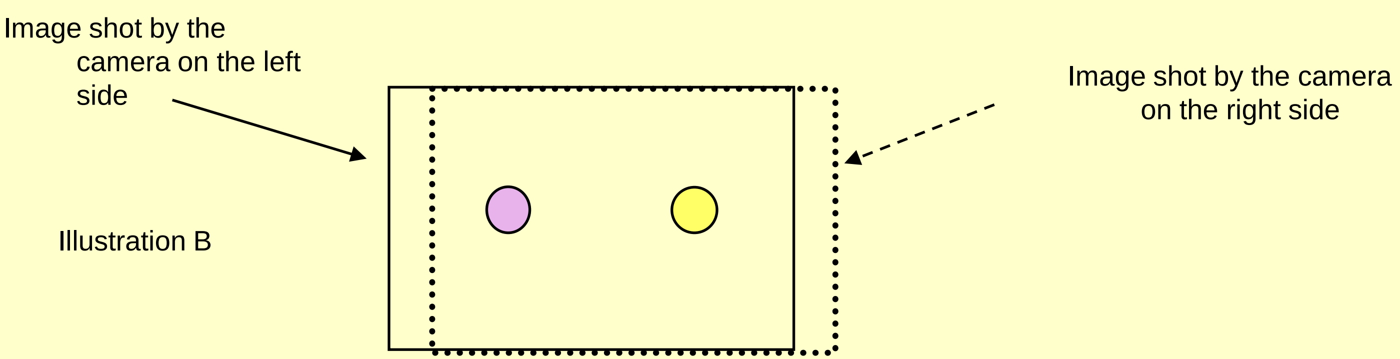
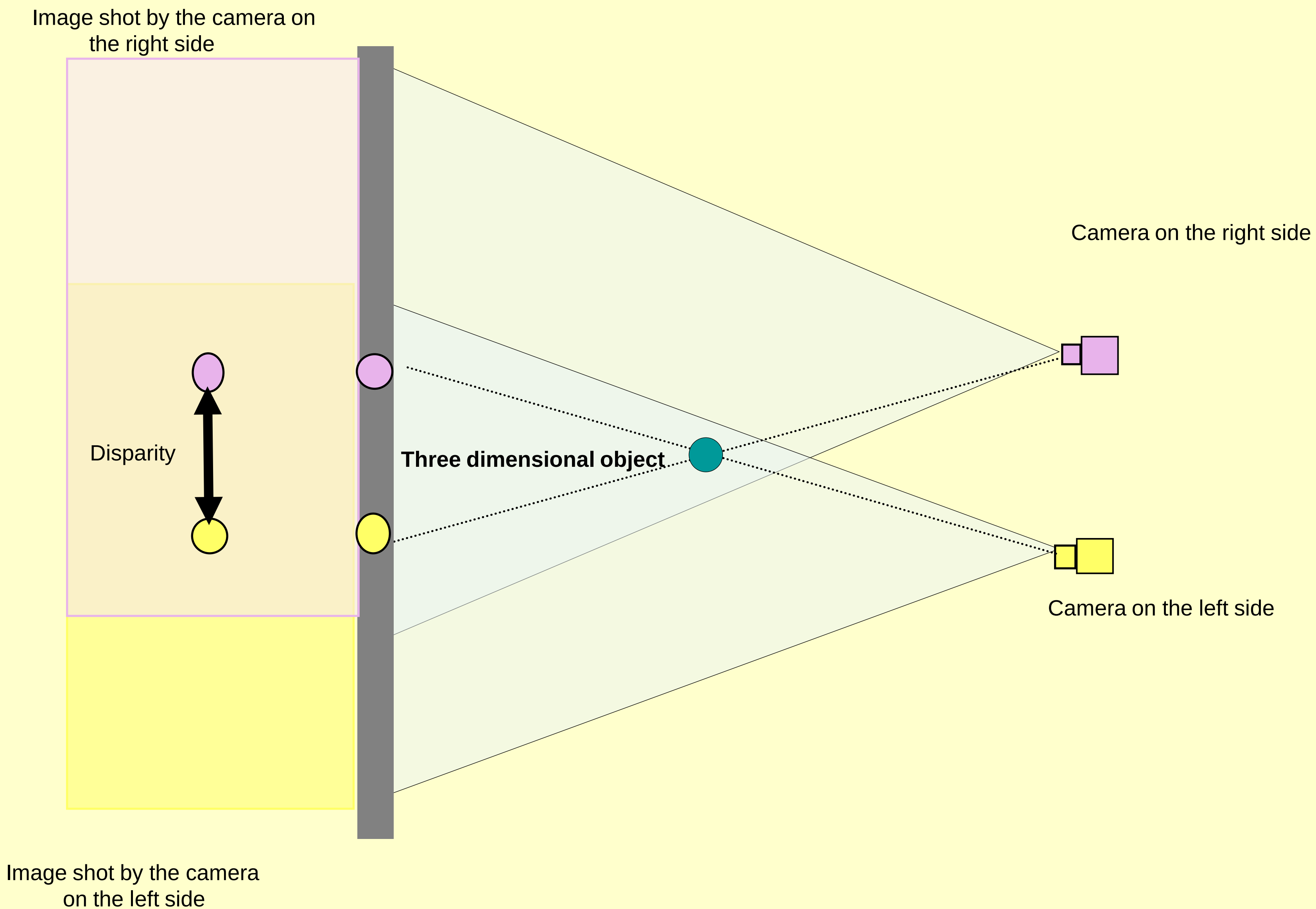


Illustration B



<Note 6> Camera intervals and disparity
The smaller the camera interval becomes, the smaller the binocular disparity becomes.



<Note - 7> Reference data to prevent motion sickness (No.1)

Explanation

(1) As in the case when viewing 2D images, by viewing stereoscopic images, some people claim discomfort that feels like the motion sickness they feel in a vehicle. 3

It is called 3D motion sickness or visually induced motion sickness (VIMS). There are no experimental results which directly relate to sickness concerning stereoscopic images;

however, it is recommended to refer to research data of motion sickness concerning 2D images to prevent 3D motion sickness.

(2) 30 degrees of an expected horizontal angle is equivalent to the standard viewing distance for high definition TVs (viewed from the distance which is three times the height of the screen).*

At home, people often watch TV from a distance which is closer than the advisable level of the standard viewing distance;

therefore, when they are viewing image content which has rotations, or horizontal or vertical oscillation, they may feel as if they are actually moving (visually induced self-motion sensation) which may lead to discomfort with the sensation.

** The following is the standard viewing distance for high definition TVs depending on the size of screens for your reference.*

32-inch => around 120 cm, 37-inch => around 140 cm, 46-inch => around 170 cm,

52-inch => around 190 cm, 65-inch => around 240 cm

(3) Concerning rotation, and horizontal or vertical oscillation, it is said that motions at 30-60 degrees/second often induce motion sickness; therefore, it is safer to avoid continuously watching images which have such motions.

Example: Images which rotate the entire screen at the speed that one rotation is made which is around 6 - 12 seconds fall under the category.

When they are viewed from the standard viewing distance, images which cross the screen at around 0.5 - 1 second also fall under the category.

Reference

H. Ujike: SABS JournalVol.35, p6-8(2005)

H.Ujike, T.Yokoi, S.Saida： Proc.26th Annual Int .Conf. IEEE EMBS, p2399-2402(2004)

(Refer to Note 7 on the following page for an abstract of research data concerning 2D.)

<Note - 7> Scientific data concerning motion sickness (No.2)

Hu et al. (1989) reported that yaw motions which are visually given by using rotating drums had the greatest impact when the speed was 60 degrees/second.

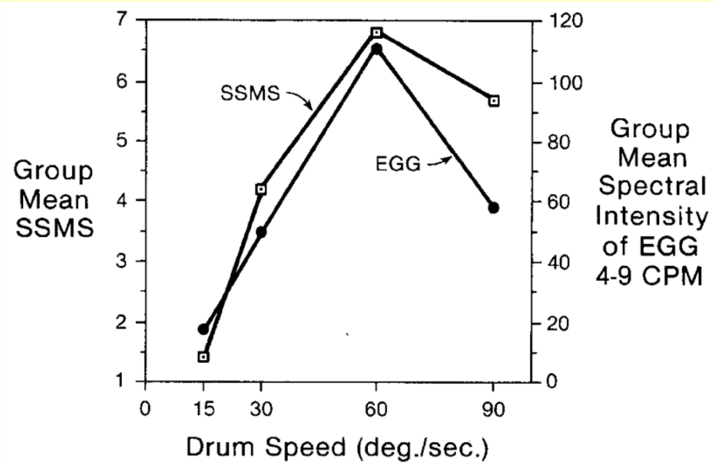
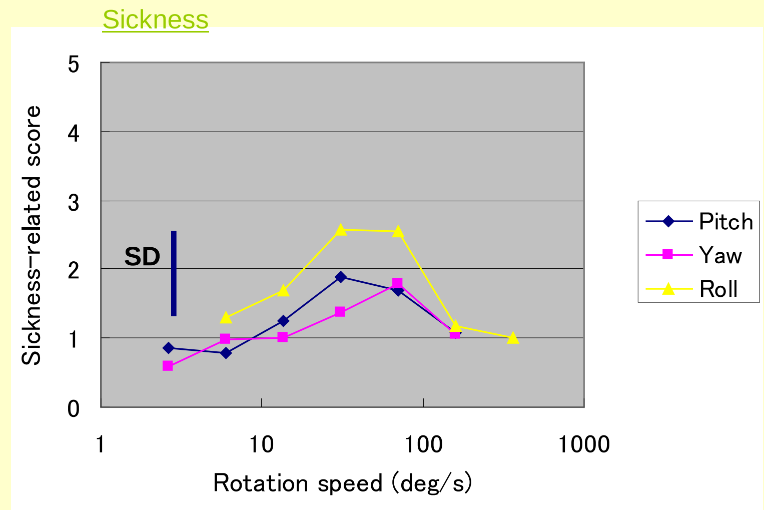


Fig. 1. The effects of four drum rotation speeds on subjective symptoms of motion sickness (SSMS) and on tachygastria power expressed as spectral intensity of EGG activity at 4–9 cpm.



Hu S, Stern RM, Vasey MW, Koch KL: Motion sickness and gastric myoelectric activity as a function of speed of rotation of a circular vection drum. Aviat Space Environ Med, 60(5), 411-414 (1989).

When oscillating scenes created by using computer graphics at the amplitude of 60 degrees at the speed of 30 degrees/second, the scores recorded of discomfort based on subjective assessments increased over time.

All rotations around a pitch axis, yaw axis and roll axis basically induced motion sickness at a similar level.

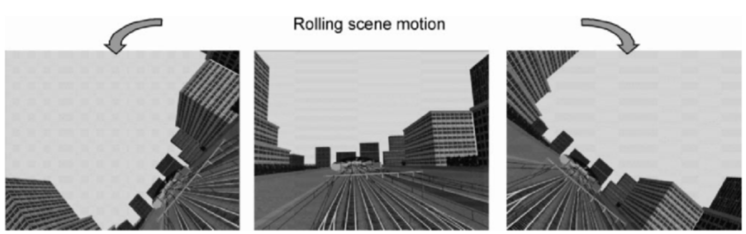


Fig. 1. Sample scenes of what the participants saw on the *head-mounted display* during scene oscillations in the roll axis. The virtual environ contains some buildings, a train station, tracks, cables, and bridges.

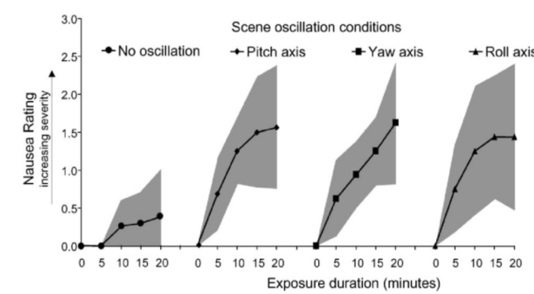


Fig. 2. Mean nausea ratings obtained in the four scene oscillation conditions as functions of exposure duration (data from 16 participants, ± one standard deviation are shown).

Lo WT, So RHY: Cybersickness in the presence of scene rotational movements along different axes. Applied Ergonomics, 32(1), 1-14 (2001).

Guidelines for manufacturers for comfortable viewing of stereoscopic images

<GL - 14> Crosstalk

<GL - 15> Recommended frequency for the time division technique

<GL - 14> Crosstalk

For equipment which displays stereoscopic images by using binocular disparity, development of equipment with the smallest possible crosstalk between the images for the left eye and those for the right eye is recommended.

Crosstalk: The percentage of the leakage of images for the right eye to the left eye and that for the left eye to the right eye (%).

Explanation: If crosstalk is large, content with strong contrast leads to double images which cause eye fatigue.

By using equipment with a smaller crosstalk, stereopsis can easily be achieved which enables a large amount of disparity.

Small crosstalk is one of the important factors for evaluation when introducing 3D displays.

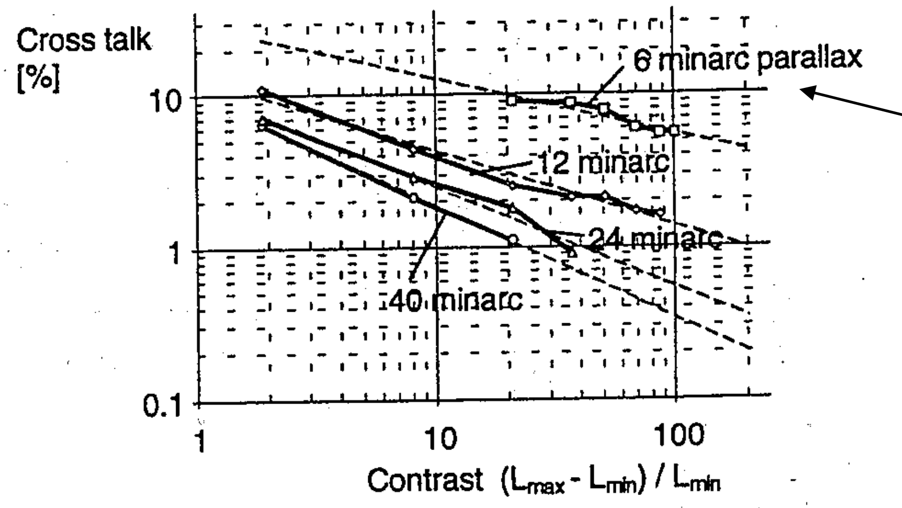


Fig. 5: Visibility thresholds for cross talk as a function of local contrast and binocular parallax (local change in depth).

Unit for binocular disparity minarc = minute＝1/60 degrees

The figure on the left is the result of an experiment conducted by the Heinrich-Hertz-Institut Berlin which shows the percentage of crosstalk (vertical axis), and the threshold limit of the contrast which leads to double images and of binocular disparity.

This result shows that it is necessary to select displays with a small crosstalk to comfortably view 3D images.

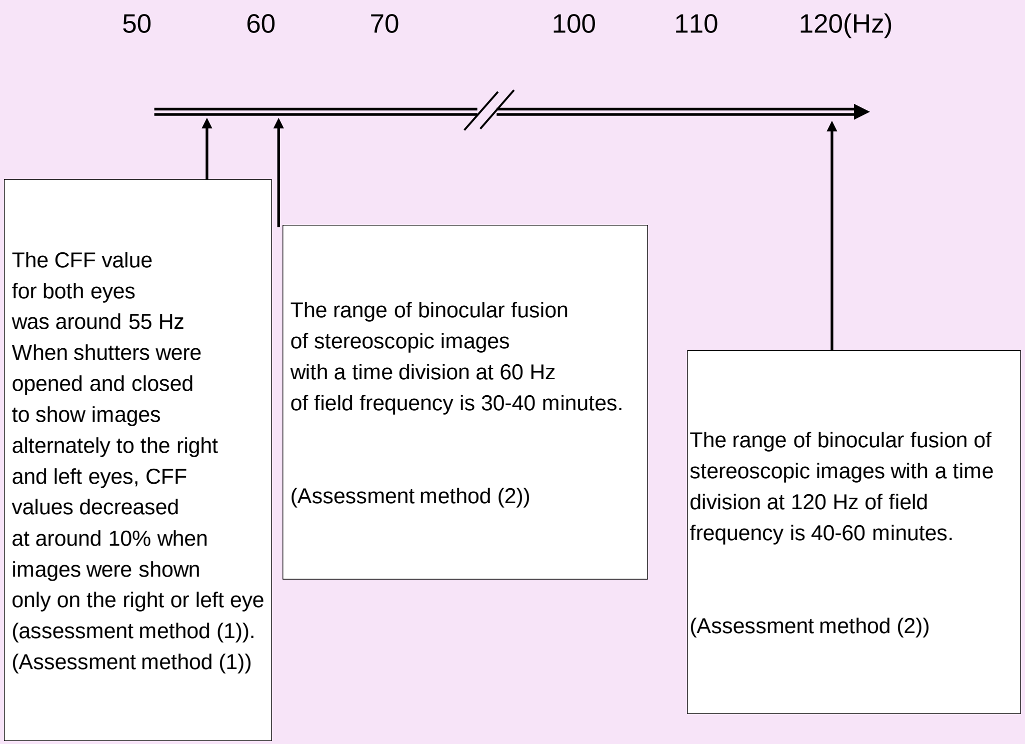
S. Pastoor, "Human factors of 3D images: Results of recent research at Heinrich-Hertz-Institut Berlin, Proceeding of IDW'95 3D-7,pp69-72(1995)

<GL - 15> Recommended frequency for the time division technique

For 3D equipment that requires use of liquid crystal shutter glasses, if the switching frequency is too low, viewers may feel flickering which may cause photosensitive epilepsy or lowers the binocular fusion limit.
Personal differences are large in terms of how flickering is felt which also depends on the surrounding environment; however, it is recommended to use equipment with the highest possible frequency for switching.
Explanation: Flickering may induce photosensitive epilepsy; therefore it requires special attention.
If switching frequency is sufficiently high, flickering can be avoided; however interference between opening and closing of shutters of glasses and fluorescent bulbs without inverters also requires attention in terms of preventing flickering.
It is known that the brighter the screen becomes, the easier it is to feel flickering.

The following data is an excerpt from JEITA's guidelines.

CFF: Critical Flicker-fusion frequency:



<u>(1) CFF values for both eyes</u>

CFF values were measured by turning the entire screen on and off at 30 degrees of the horizontal angle of the visual field (Brightness 380, 5.5 cd/m2) .

<u>(2) Measurement of the range of binocular fusion</u>

<u>Required frequency for shutters for time division stereopsis</u>

Slides with random dot patterns and square patterns were set on a stereoscope and liquid crystal shutters were used to achieve stereopsis.

By changing the drive frequency of liquid crystal shutters, the minimum frequency required to achieve stereopsis was measured.

Acknowledgment

The following results of research were used as the basis of preparation of these guidelines.
We would like to express our sincere gratitude to the Ministry of Economy, Trade and Industry, JKA, the Mechanical Social Systems Foundation, the Japan Electronics and Information Technology Industries Association (JEITA), the Ministry of Internal Affairs and Communications and related organizations which provided long-term support for these research and development activities.

(1) Projects committed to by the Mechanical Social Systems Foundation (1996 - 2002)
"A Feasibility Study Report on Three-Dimensional-Image Influence on Factors of Human Organism and Results of Framework for Guideline", the "Tentative Proposals for Guidelines Relating to 3D Images" (1999) and database for supporting content creation (2001) by the Japan Electronics and Information Technology Industries Association.

(2) Report for projects concerning standards and conformity assessment by the Ministry of Economy, Trade and Industry (2003 - 2005)
"Research on standardization of assessments on the biological safety of stereoscopic images" ISO IWA3 (2005) by the Advanced Industrial Science and Technology (AIST)
(3) Reports on research and development committed to by the Ministry of Internal Affairs and Communications (2003 - 2005)
"Technologies to avoid adverse effects of images on human bodies" by the University of Tokyo, NHK (Nippon Hoso Kyokai (Japan Broadcasting Corporation)), Hitachi, Ltd., Toshiba Corporation, and Sharp Corporation
(4) Projects committed to by JKA and the Mechanical Social Systems Foundation (2006 - 2008)
"Feasibility Study on Development of Verification Systems for Guidelines of Motion Sickness" and others by the Japan Electronics and Information Technology Industries Association
(5) "International cooperative projects between Japan and the US for low carbon revolution, and research for international standardization of fundamental technologies for energy conservation" by the Ministry of Economy, Trade and Industry
Project to promote research about infrastructure for comfortable 3D (2009 -)
Draft for revision of the 3DC Safety Guidelines 2010, the literature concerning biomedical effects of 3D
Image Evaluation System (Non Profit Organization), You-Staff, Co., Ltd.

April 2010
3D Consortium
Safety/Guidelines Section