Ergonomic Design Guidelines for Flat Panel Display Televisions

Special Committee on FPD-TV Ergonomics

Japan Ergonomics Society

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These guidelines are based on the results of laboratory experiments and field surveys, which were supported by NEDO (New Energy and Industrial Technology Development Organization)

1. Introduction

Cathode ray tube (CRT) televisions are rapidly being replaced by large flat panel LCD and plasma televisions that support high-definition digital broadcasts. Development of high definition television (HDTV) began after the 1964 Tokyo Olympics, with the first standard proposed in 1972 by the International Telecommunication Union (ITU), formerly the Consultative Committee on International Radio (CCIR). Based on experimental research performed at that time, initial ergonomic specifications were established for items such as screen visual angle, aspect ratio, viewing distance, and resolution[1)–6)]. Because that research predominantly used static images projected from film, however, and broadcasters, not manufacturers, developed the proposed standard, certain ergonomic design issues that arise during actual television viewing were likely not taken into consideration. Given the recent full transition to digital terrestrial broadcast and trends toward viewing television on state-of-the-art large flat panel displays, new ergonomic design guidelines that take into consideration current television viewing environments are needed.

Establishment of such guidelines would not only provide viewers with better conditions for watching flat panel televisions, but also contribute to lowering energy consumption[7), 8)]. Ergonomic design guidelines benefit television manufacturers by promoting healthy development of display technologies, and benefit consumers through the establishment of conditions for comfortable home television viewing with lower energy costs.

2. Intended audience

These Guidelines were created as a reference for television engineers (including those performing work related to displays, image processing, image quality evaluation, appliance design, quality control, etc.) to design and develop flat panel televisions in accordance with ergonomic considerations that will allow viewers to watch television in appropriate, comfortable conditions. These Guidelines are also intended to serve as a reference for content creators, broadcasters, and broadcast technicians in regard to the actual viewing conditions under which televisions are best watched.

3. Contents

4. Perspectives on ergonomic design for flat panel televisions

One of the most important goals of ergonomics is human-centric product design. Such design requires a firm understanding of the conditions under which the product will be used, and design optimization that will maximize user satisfaction. Many product specifications are mutually related, meaning that ergonomic design must be comprehensively implemented from the initial stages of product development. Figure 1 shows an overview of ergonomic design for flat panel televisions.

First, designers must have a sufficient understanding of the viewing environment. When designing display luminance, luminance contrast, and color reproduction, for example, lighting conditions affect not only viewer adaptation to luminance and color, but also the display itself. Survey data related to viewing distance and angle are also vital when designing features related to display luminance and viewing angle. These Guidelines provide a wide scope of data related to home television viewing environments and conditions, and furthermore provide conditions for maximizing viewer satisfaction based on multifaceted laboratory experiments.

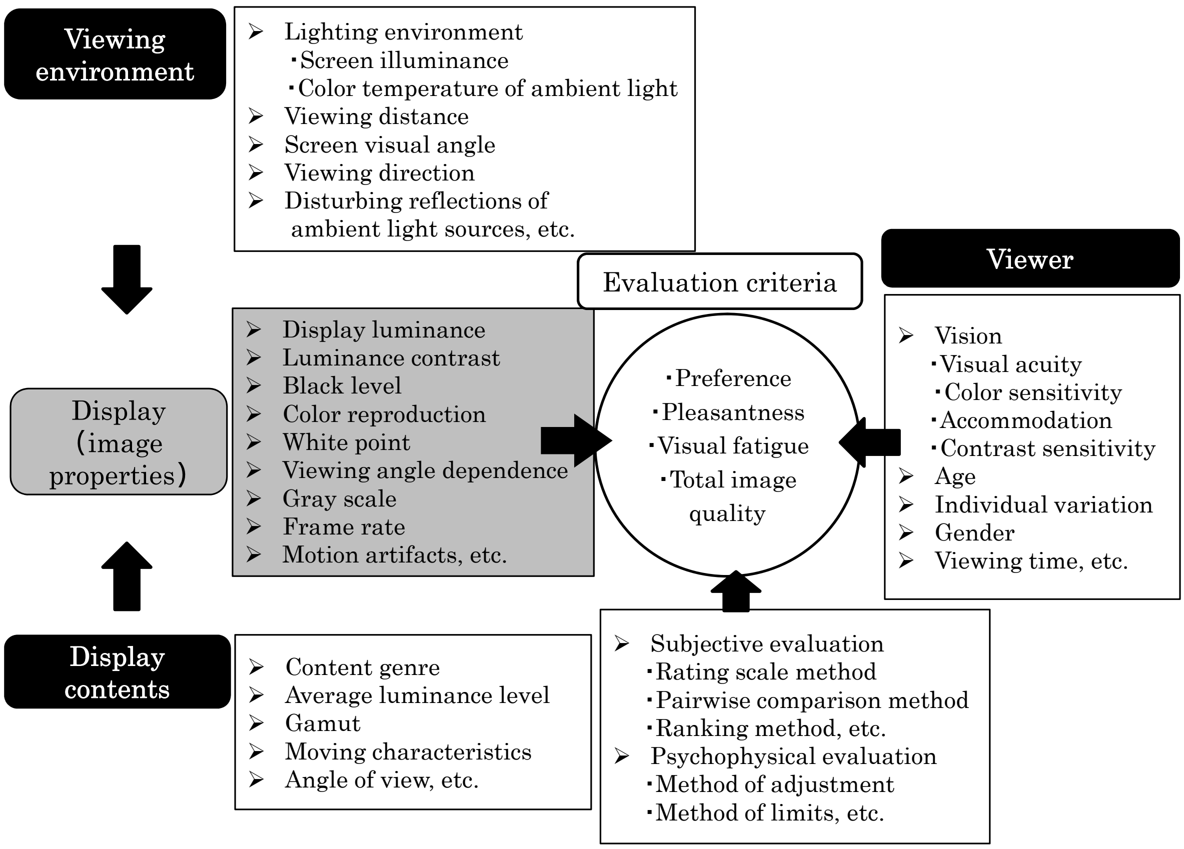


Figure 1. Overview of flat panel television ergonomic design.

Second, characteristics of the displayed image must be known. For example, required luminance and luminance contrast values are strongly influenced by the image's average luminance level (ALL) after gamma correction. These Guidelines analyze terrestrial digital broadcast signals and find statistical values for ALL to allow for consideration of such characteristics.

Third, the influence of viewer characteristics, particularly visual characteristics, must be taken into consideration. Given the ongoing aging of society in many countries, changes in vision that occur with increased age are of particular concern. Even among individuals within a particular age group there is significant variation in optimal settings for various design elements, and consideration of how technology can adapt to such variation is another topic for ergonomic design. These Guidelines were designed to allow reference to the distributions, standard deviations, and percentiles for such data.

Finally, there is a need to assess the above factors through experiments with a variety of participant groups. Where possible, such assessments should involve at least 15 participants who are not display experts for each study. Factors related to the ergonomic design of flat panel televisions such as preference, comfort, fatigue, and overall image quality require quantification using methods from psychological evaluation such as ratings scales and pairwise comparisons. For some design elements, psychophysical experimentation methods such as methods of limits and adjustment may be applied.

When presenting guidelines for design elements, these Guidelines use perspectives such as those described above to describe viewing environments and conditions. Note that these Guidelines were developed using survey results obtained within Japan, and therefore may not be applicable to the use of flat panel televisions in overseas markets. The fundamental perspective of these Guidelines, however, is applicable to the design of flat panel televisions in any country. To that end, we have included as an annex the results of surveys related to flat panel television viewing from six countries (Brazil, China, India, Japan, the United Kingdom, and the United States). Comparison of differences in television viewing environments between Japan and other countries should allow for the application of the Guidelines to the design of flat panel televisions for overseas markets.

5. Display luminance

Television screen settings related to appropriate display luminance are important for reducing visual discomfort and energy consumption. Excessive luminance not only increases the risk of visual fatigue[9)–11)], but also wastes electricity[7), 8)].

As shown in Figure 2, optimum display luminance depends on a number of factors, including ambient luminance, angular screen size, ALL after gamma correction, and viewer age[7), 8), 12)–17)]. Here, we define optimum display luminance as the white luminance (including components of reflected luminance) after the viewer has adjusted the display luminance to the most preferred brightness when a particular image is displayed.

Ambient illuminance determines the viewer's luminance adaptation level, and also affects black level luminance and luminance contrast. When designing displays, the influence of ambient illuminance is estimated by taking screen illuminance as the vertical plane illuminance incident to the screen.

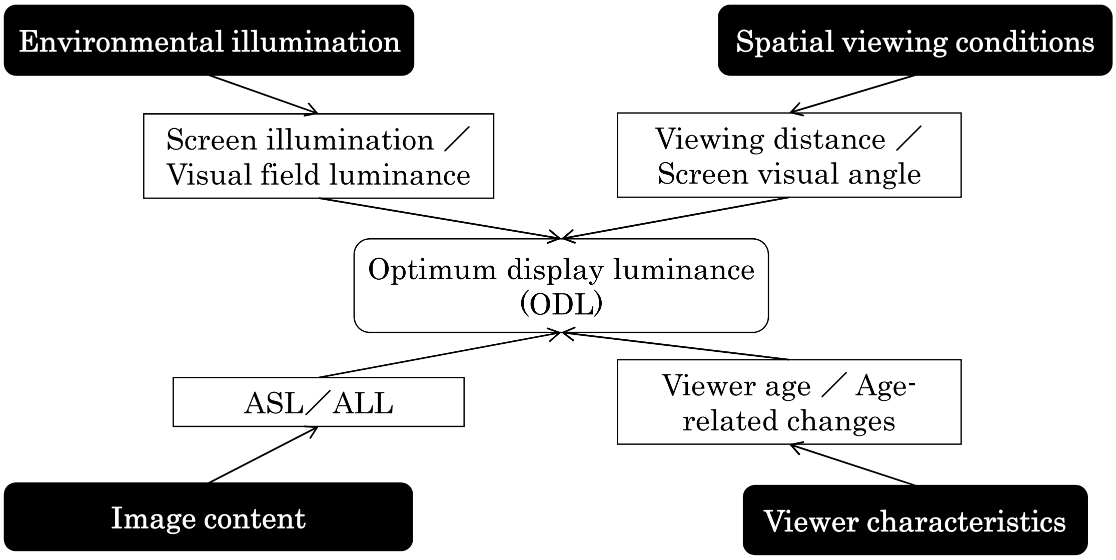


Figure 2. Primary factors affecting the optimum display luminance of television screens.

(1) Screen illuminance

Figure 3 shows the distribution of screen illuminance settings for televisions in living rooms in Japan[7), 8)]. The distribution is based on per-minute measurements of powered-on televisions in 77 households, combining daytime and nighttime measurements. Values are 20 lx at the 10th percentile, 92 lx median, and 305 lx at the 90th percentile. Appropriate display luminance should be adjustable according to this illuminance distribution. Figures 4 and 5 show screen illuminance distributions divided between daytime and nighttime measurements, respectively. The respective mode values (78 lx and 71 lx) are nearly identical, but median values are 123 lx for daytime and 74 lx for nighttime, and 90th percentile values are 518 lx and 140 lx, respectively.

It is furthermore necessary to allow adjustment of appropriate display luminance while viewing in low illumination or dark environments, such as found in home theaters. As shown in the Annex, while only 1% of Japanese households view television with lights turned off, 10% of households in Western countries do so[18)].

Another factor related to appropriate display luminance is the effects on viewing luminance from areas behind the screen, which is related to screen illuminance. In a typical living room, the average nighttime luminance in a 180° view excluding the television screen is 5 cd/m^2 for a screen illuminance of 30 lx, and similarly 17 cd/m^2 at 100 lx, and 50 cd/m^2 at 300 lx[7]. This is equivalent to a behind-screen wall with a reflectance of 60% (N8). As described in the Annex many households in Japan have televisions positioned facing away from south-facing windows[19], making it difficult to use screen illuminance to predict the luminance of visual field during daytime television viewing[20].

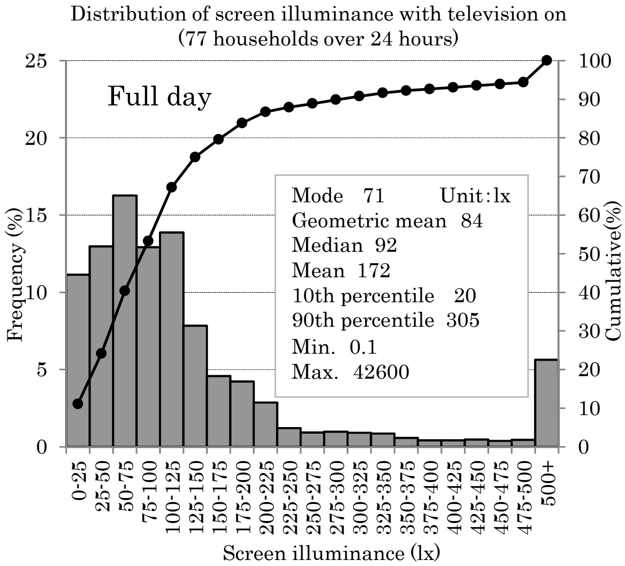


Figure 3. Screen illuminance with television on, based on per-minute measurements over 24 h in 77 households.

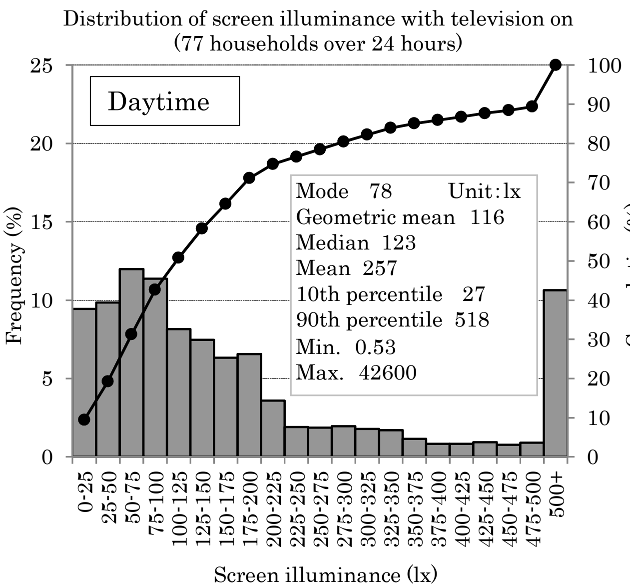


Figure 4. Daytime screen illuminance with television on, based on per-minute measurements over 24 h in 77 households.

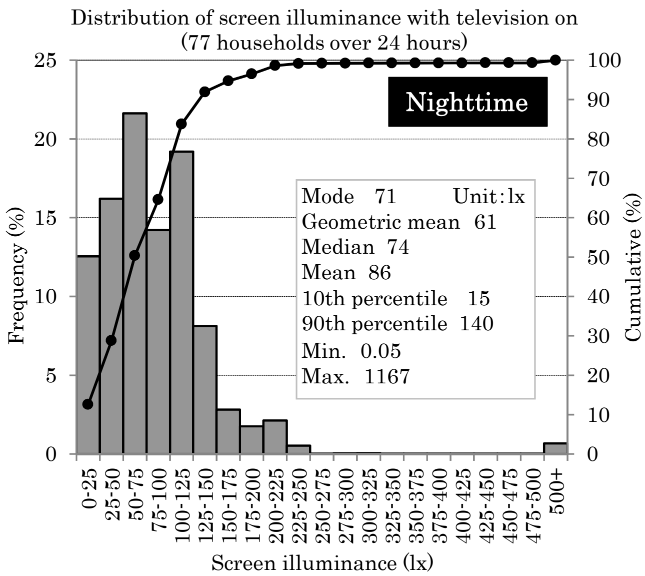


Figure 5. Nighttime screen illuminance with television on, based on per-minute measurements over 24 h in 77 households.

(2) Screen visual angle

The screen size and the viewing distance determine the screen visual angle. Table 1 shows the relationship between the screen visual angle (deg), relative viewing distance (H: screen height), and viewing distance (cm). Figure 6 shows the viewing distance for televisions in Japanese living rooms[7), 21)], for which the 10th percentile is 165 cm, the median is 252 cm, and the 90th percentile is 417 cm. The viewing distance depends more on room size and placement of sofas and other furniture than on screen size[7), 22), 23)]. It is therefore necessary to select an appropriate screen size for the viewing distance. In Section 9, the preferred viewing distance for each screen size is discussed.

Figure 7 shows a graph of measurement results for various screen sizes. Here, measurements were performed by seating a household member in the most preferred position for television viewing and measuring the horizontal visual angle to the television (angular size in degree). A 3H (three times the screen height) relative viewing distance gives a horizontal visual angle of 33°, but the data show that most households view television from a greater distance. Screen sizes around 40 in. had visual angles of around 15° to 30°, with an average of approximately 20°. As shown in Table 1, a horizontal visual angle of 20° is equivalent to a viewing distance of 5H. When viewing a 40-in. screen from about 250 cm away, the display angle is 20°.

Table 1. Relationship between horizontal visual angle (deg), relative viewing distance (H), and viewing distance (cm). Screen aspect ratios were 16:9.

Horizontal visual angle (deg)	Relative viewing distance (H)	Viewing distance (cm)					
		24 in.	32 in.	40 in.	46 in.	55 in.	65 in.
10	10.2	304	405	506	582	696	822
12	8.5	253	337	421	484	579	685
14	7.2	216	288	361	415	496	586
16	6.3	189	252	315	362	433	512
18	5.6	168	224	280	321	384	454
20	5.0	151	201	251	289	345	408
22	4.6	137	182	228	262	313	370
24	4.2	125	167	208	240	286	338
26	3.9	115	153	192	221	264	312
28	3.6	107	142	178	204	244	289
30	3.3	99	132	165	190	227	269
32	3.1	93	124	154	178	212	251
34	2.9	87	116	145	167	199	235
36	2.7	82	109	136	157	187	221
38	2.6	77	103	129	148	177	209
40	2.4	73	97	122	140	167	198

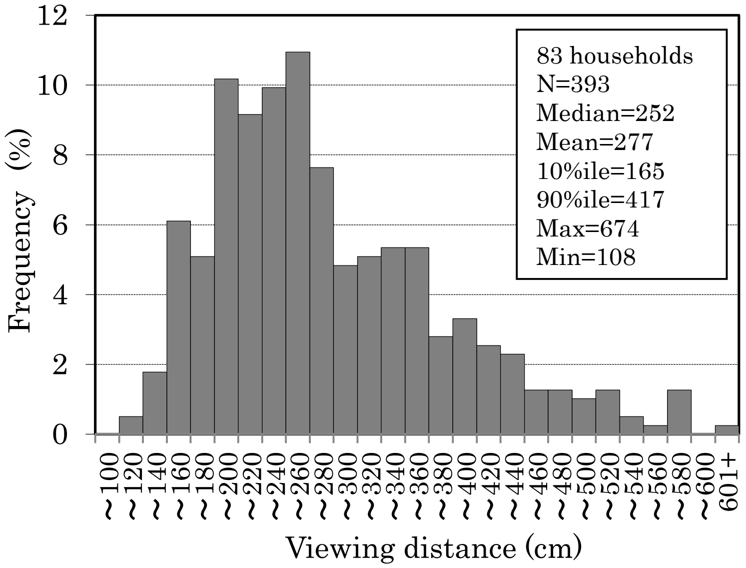


Figure 6. Viewing distance distribution for 393 members of 83 households.

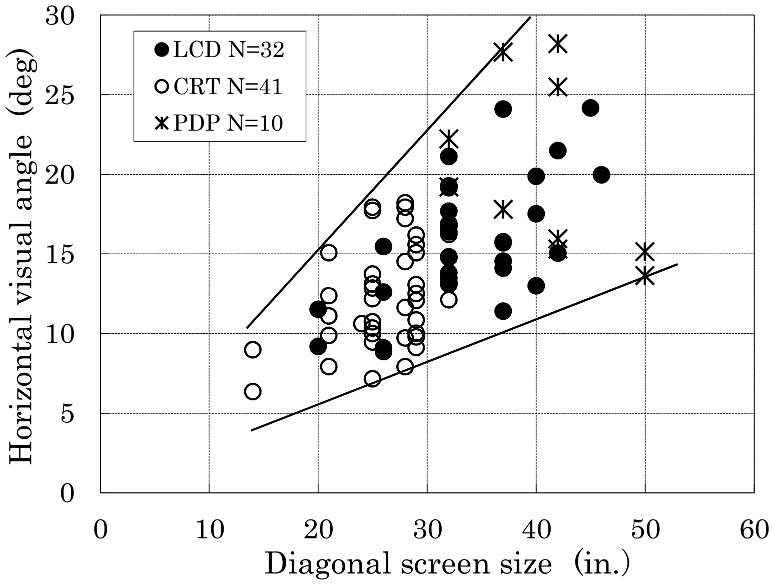


Figure 7. Relationship between diagonal screen size (in.) and horizontal visual angle (deg) for the most preferred television viewing positions in 83 households.

(3) Average luminance level

After a device receives a broadcast image signal, it applies gamma correction based on the gamma value of the received image, and converts the results to an ALL that takes a fully white screen as a relative value of 100. A typical decoded gamma is approximately 2.2. The ALL of an image varies with the type of broadcast, but analysis of terrestrial digital broadcasts of five Japanese channels for one week resulted in an overall average of approximately 25%. Figure 8 shows a distribution of ALL values for all broadcast frames from the five major Japanese television stations during one week in 2009[24]. The 5th percentile is 5%, and the 95th percentile is 44.8%. Average signal level (ASL) before gamma correction was 44.8% overall, and 45.9% during prime time, approximately the same as ALL values recorded over 200 days of satellite broadcasts[25]. Note, however, that average luminance may be higher for television shows broadcast in Japan; when overall ASL was measured over 40–60 h of broadcasts in the United States, the United Kingdom, Australia, France, and Japan as part of establishing measurement methods for the television power consumption measures of IEC 62087[26], the obtained value was 34%, approximately 10% lower than the Japanese case. Data on viewing frequencies of shows by broadcast type are included as the Annex. As compared with other countries, viewership of variety shows is particularly high in Japan, as is their frequency of broadcast. In the United States, viewership of movies is the highest. The relatively high ASL values seen in Japan may be due to such differences in broadcast genre preferences.

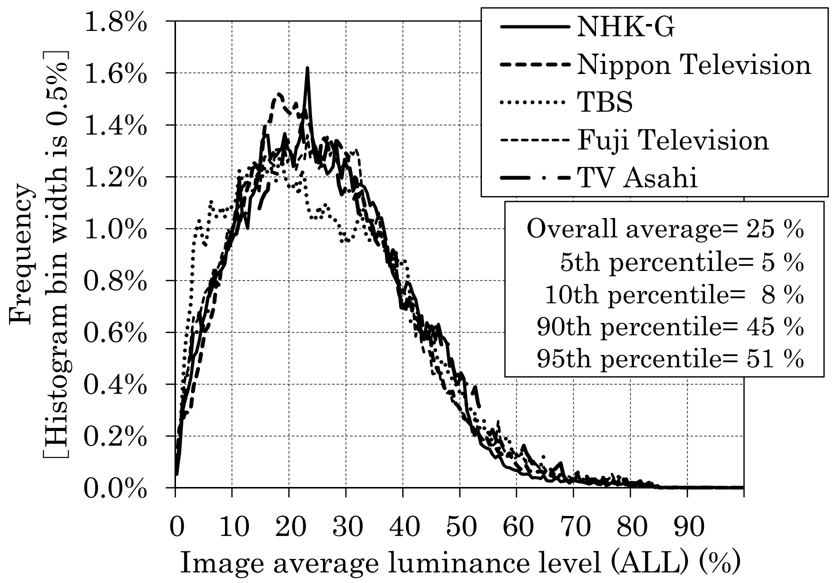


Figure 8. Distribution of ALL values for all broadcast frames from the five major Japanese television stations (data measured between July 31 and August 7, 2009).

(4) Multiple regression models of optimum display luminance

To find optimum display luminance (ODL) values we performed multifactor laboratory experiments with participants of various ages, using the above-described screen illuminance, visual angle, and image ALL as test variables[7), 8)], and found a double logarithmic, linear relationship between each of these three factors and ODL. With respect to ODL, as each factor acts independently, we were also able to derive a multiple regression model to predict ODL. Here, ODL refers to the white luminance (including components of reflected luminance) during display of a specific image with display luminance set to the viewer's most preferred brightness.

Equation (1) is the model for a participant group with average age 22. Equation (2) is a similar model for elderly viewers, created using a participant group with average age 71. These models were found from the geometric mean of values from 24 participants from each age group, so that ODL distributions would be lognormal under each test condition as set by the participants. In terms of geometric standard deviations, variation between participants was approximately 0.6 times the geometric mean at the –1 standard deviation level, and 1.7 times the geometric mean at the +1 standard deviation level. In other words, approximately 68% of test results should fall within this range. For example, given an ODL of 100 cd/m^2, roughly 68% of participant data should fall within the range 60–170 cd/m^2. Such individual differences should be taken into consideration when designing the range over which display luminance can be adjusted.

• ODL regression model for young group (average age 22).

$$\log PL = 2.40 + 0.27 \log E - 0.22 \log SA - 0.32 \log AL \quad (1)$$

$(F(3,23)=1051,\ p<0.001,\ R^2=0.99)$

• ODL regression model for elderly group (average age 71).

$$\log PL = 2.87 + 0.13 \log E - 0.34 \log SA - 0.21 \log AL \quad (2)$$

$(F(3,23)=141,\ p<0.001,\ R^2=0.94)$

Here, PL is the ODL (cd/m^2), E is the screen illuminance (lx), SA is the horizontal visual angle (deg), and AL is the image ALL (%).

Figure 9 is a contour map based on the young group ODL model of Equation (1), showing ODL (white luminance) according to screen illuminance and visual angle when ALL is taken as the 25% average level of general broadcasts. Figure 10 similarly uses the elderly group ODL model of Equation (2).

Figure 11 shows ratios of elderly to young ODL values, indicating the differences in ODL between young and elderly viewers under the various conditions. Of particular note is that the differences between young and elderly viewers increase as screen illuminance values and visual angles decrease.

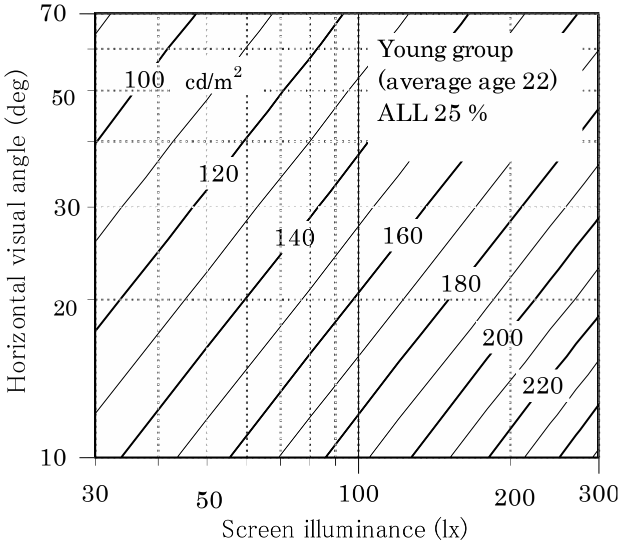


Figure 9. ODL by screen illuminance and screen visual angle, young group (average age 22) for 25% ALL.

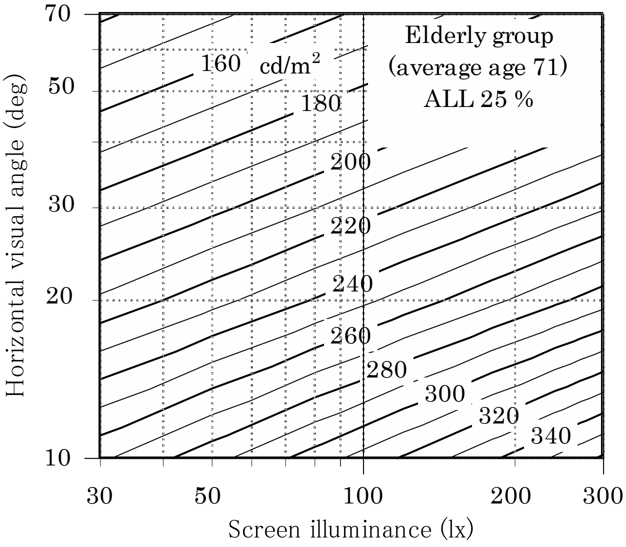


Figure 10. ODL by screen illuminance and screen visual angle, elderly group (average age 71) for 25% ALL.

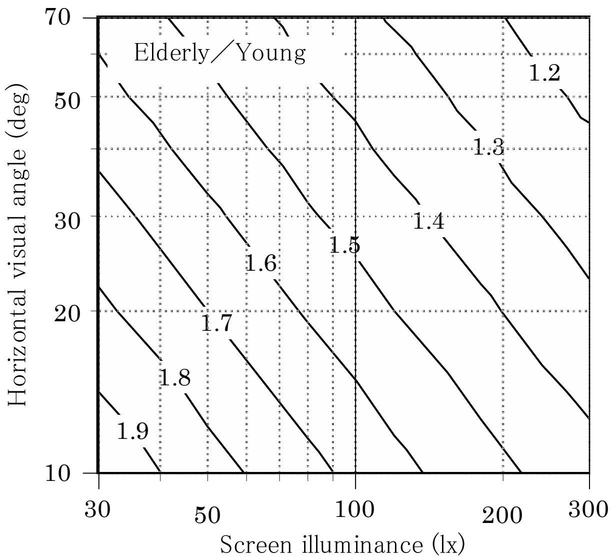


Figure 11. Ratio of elderly and young participant ODL for screen illuminance and screen visual angle (ratio of values from Figures 9 and 10).

(5) Effects of aging on optimum display luminance

Figure 12 shows the ODL values after performing a similar experiment with a wide range of ages. These values were obtained with screen illuminance values of 30, 100, and 300 lx, the actual average horizontal visual angle of 20° (5H at the viewing distance), and ALL of 25%. The figure shows that as age increases ODL increases linearly, indicating the necessity of allowing setting of display luminance according to user age. As described above, there are furthermore significant differences in ODL among individuals. Table 2 summarizes the geometric mean and geometric standard deviation for ODL values, a summary that is possible because ODL closely follows a lognormal distribution. Approximately 68% of participants will fall within the range of ±1 geometric standard deviations. These values for individual variation should be considered when setting the range of luminance adjustments.

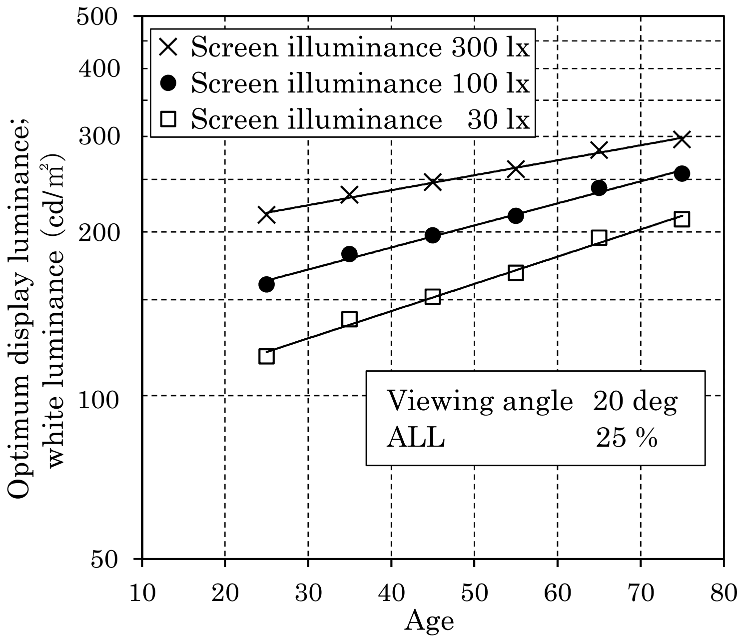


Figure 12. Television ODL as a function of age, under typical real-world viewing conditions of 20° horizontal angle (5H viewing distance) and 25% ALL.

Table 2. Television ODL (white luminance) by age, for actual viewing conditions of 20° horizontal angle (5H viewing distance) and 25% ALL. Because ODL closely follows a lognormal distribution, values are given as geometric means and geometric standard deviations (GSD). Approximately 68% of participants will fall within the range of ±1 GSD.

Age group	Screen illuminance (lx)								
	30			100			300		
	-1GSD	Geometric mean	+1GSD	-1GSD	Geometric mean	+1GSD	-1GSD	Geometric mean	+1GSD
20s	71	118	201	96	160	273	129	215	365
30s	83	138	234	109	182	309	140	234	398
40s	91	152	258	118	197	334	148	247	419
50s	101	168	286	128	214	363	157	261	444
60s	117	195	332	144	241	409	170	283	482
70s	127	211	359	154	256	436	177	296	503

Units : cd/m²

6. Black level luminance

Black level luminance is an important factor in high-quality image display. The level of black level luminance required to prevent the “floating black” effect depends on the image content and environmental lighting conditions[27]. The conditions that result in the lowest black level luminance demands are a full black screen under low illumination[28]. In other words, if the floating black effect does not arise under these conditions, then it will not for any image displayed. Figure 13 shows the results of testing using a 32-in. LCD television in a nighttime family living room environment[29]. The values indicate the black level luminance that does not result in floating blacks when viewing an all-black screen from a 3H viewing distance. Here, laboratory walls were covered with N8 (60% reflectance) cloth, similar to conditions commonly found for walls behind televisions in residential living rooms. To minimize the effects of reflected luminance components due to specularity of the screen, the area in front of the screen (viewer’s side) was covered with black velveteen cloth, allowing for almost no difference between antiglare and clear processed surfaces. A test participant viewed an LCD television through a hole cut in the center of the cloth and adjusted LCD backlighting until floating blacks were no longer perceptible thereby finding the appropriate black level luminance value. Figure 13 shows the black level luminance values that were the target of this experiment.

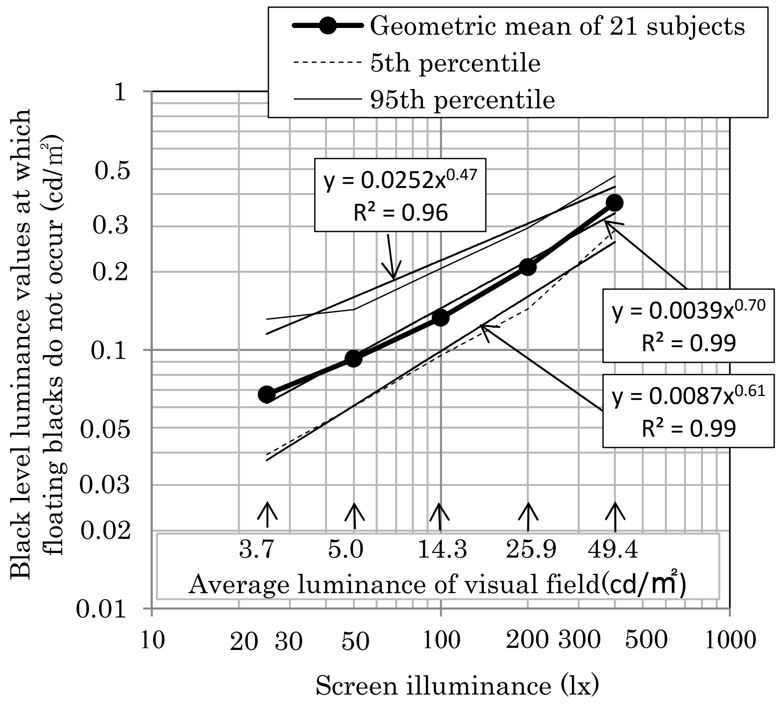


Figure 13. Luminance values at which floating blacks are not detectible for a full screen black display. Values are geometric means and percentiles for 21 individuals viewing a 32-in. LCD television from 3H (33° horizontal angle). Wall behind the screen is N8 (60% reflectance), the approximate average of living room walls.

The black level luminance required during image display also depends on the ALL of the image itself, so it is not necessary to lower luminance to these values for every image[27]. For television displays, the ratio of black level luminance and white luminance is often taken as the contrast for device specifications. Using ODL levels as a basis of evaluation can allow for dynamic range display luminance to meet display demands. Luminance contrast is discussed in the following section.

7. Luminance contrast

The luminance contrast required for a television display can be defined as the ratio between the ODL and the black luminance level required to prevent floating blacks on an all-black screen under a given set of viewing conditions. This means that the display luminance required for a display will dynamically change according to current conditions, and that the ratio of the minimum and maximum luminance for a specific image cannot be used. Table 3 shows the values for luminance contrast required for a display with an ODL as discussed in Section 5, and a black level luminance that does not result in floating blacks, as discussed in Section 6 (values are the former divided by the latter). In the case of transmissive LCD televisions, these values are the luminance contrast required by the panel with no backlight control.

Under 10th percentile screen illuminance (20 lx) and 5th percentile average luminance for a typical broadcast (5% ALL), the required luminance contrast is approximately 3200. Figure 14 shows a graph of needed luminance contrasts according to screen illuminance and the ALL of a displayed image. When ALL and ambient illuminance are low, the required contrast is high, but under actual viewing conditions, 5- and 6-figure luminance contrasts are somewhat over-engineered from an ergonomics standpoint. Note, however, that here we have not taken into consideration the reliance of display and black level luminance on viewing angle. Section 12 discusses dependence of display characteristics on viewing angle.

Table 3. Required luminance contrast for given screen illuminance and image ALL. Required luminance contrast = ODL/black-screen luminance required to prevent floating blacks.

Screen illumiance (lx) ↓	Optimum display luminance, white luminance (cd/m²): Geometric mean of ALL values for 20 viewers age 20–29 at a 20° viewing angle			Black level luminance required to prevent floating blacks: Luminance for an all-black screen (cd/m²)	Required luminance contrast: Optimum display luminance / Black level luminance required to prevent floating blacks		
	Image ALL (%)			Geometric mean for 21 viewers age 20-29	Image ALL (%)		
	5	25	51		5	25	51
	A	B	C	D	A/D	B/D	C/D
3	104	62	50	0.017	6100	3600	2900
10	145	86	69	0.035	4000	2400	1900
20	174	104	83	0.054	3200	1900	1500
30	195	116	93	0.069	2800	1600	1300
50	223	133	106	0.095	2300	1400	1100
100	269	160	128	0.144	1800	1100	800
200	325	194	154	0.220	1400	800	700
300	362	216	172	0.282	1200	700	600
500	416	248	198	0.386	1000	600	500

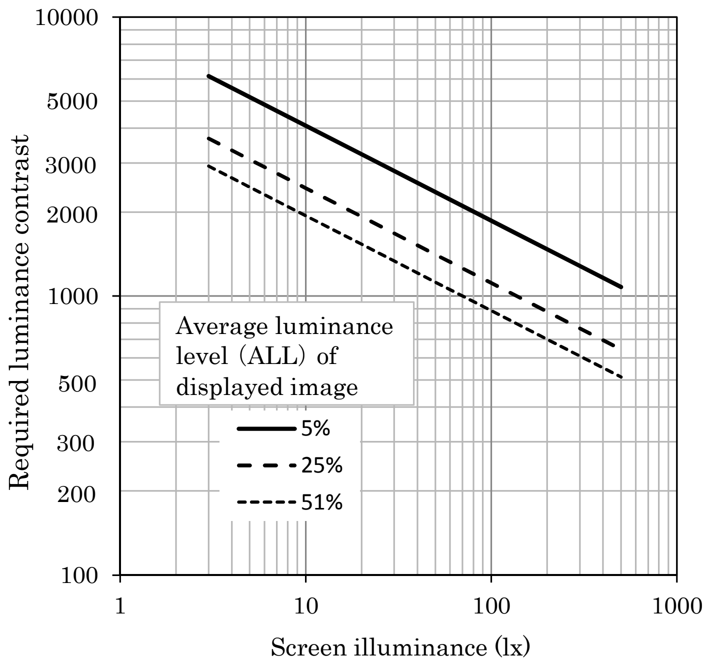


Figure 14. Required luminance contrast by screen illuminance and image ALL. Required luminance contrast is the ratio of the black luminance required to prevent floating blacks on an all-black display and the ODL (white luminance) for each ALL image.

8. White point (color temperature)

(1) Preferred color temperature

The color temperature at a preferred white point depends on the color temperature of environmental illumination, image content, screen visual angle, and display luminance[30)–32)]. Of these, the color temperature of environmental illumination has the largest effect. Figure 15 shows a distribution of relative color temperatures for incident ambient light of daytime and nighttime television screens in the living rooms of 83 households. The nighttime distribution is divided into two, to distinguish between the significant differences in color temperatures between filament-based or colored fluorescent light bulbs and 4000 K and higher white fluorescent or daylight fluorescent bulbs. Because daytime lighting includes the effects of external light, the 4000–4500 K optimum range covers a wide distribution. Preferred color temperature settings under such lighting conditions are needed.

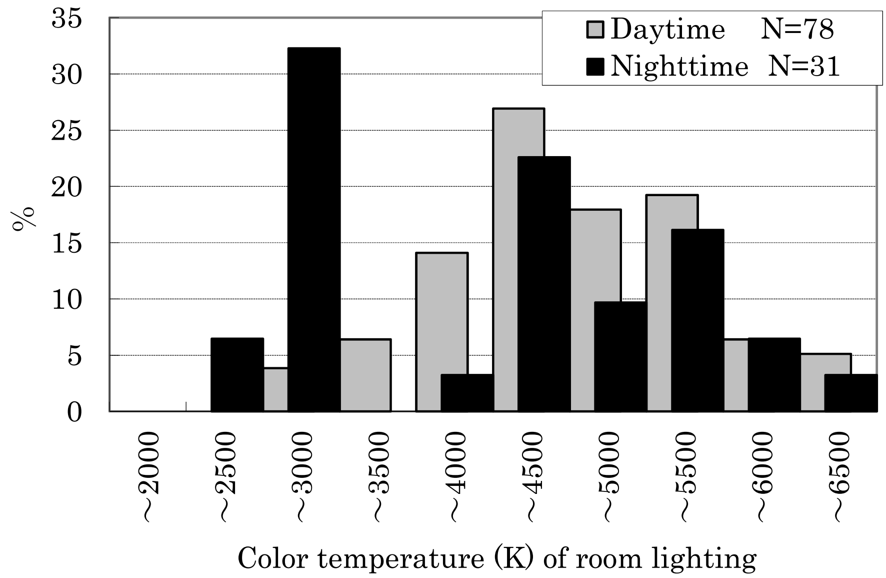


Figure 15. Distribution of color temperatures for room lighting in household living rooms. Measurements were made in 83 households, some during both daytime and nighttime.

Figure 16 shows the preferred color temperature for the white point when displaying several images under room illumination color temperatures[30)]. These results were obtained from experiments with 20 student participants, under conditions of 100 lx screen illuminance and 150 cd/m^2 white luminance as the display luminance. Preferred conditions were roughly 5500–6500 K when environmental illumination was incandescent lighting, 7000–9000 K under white fluorescent lighting, and 7500–10,000 K under daylight fluorescent lighting. Higher color temperatures were desired for natural scenes than for text screens, but on average color temperature should be set at roughly 3000 K higher than the color temperature of the room lighting.

Preferred color temperature is also affected by the apparent screen size, that is, by the screen visual angle. As Figure 17 shows, when the visual angle is small, in other words when the viewing distance is long, higher color temperatures are preferred. Figures 18 and 19 show that there is also a relationship between display luminance and ambient illuminance and that higher color temperature is preferred for higher display luminance and lower ambient luminance. This is likely because viewers prefer higher color temperature images when the screen appears to be relatively brighter.

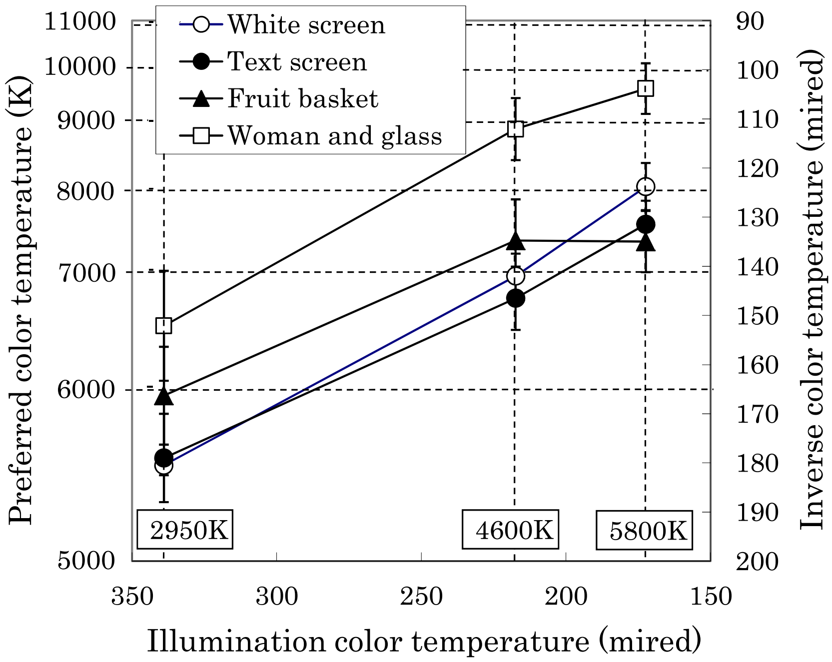


Figure 16. Illumination color temperatures and television screen preferred color temperatures. Data are the mean with ±1 standard deviation of 20 college students. Images used: “Fruit basket”, Standard Image JIS XYZ/SCID, sRGB, JIS X9204:2000 compliant; and “Woman and glass”, Standard Image JIS XYZ/SCID, sRGB, JIS X9204:2000 compliant.

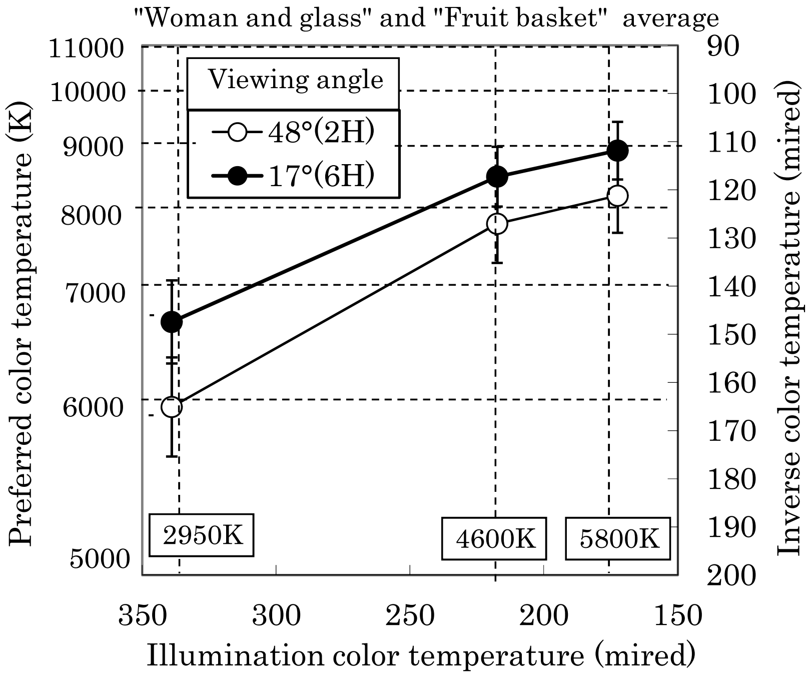


Figure 17. Television screen preferred color temperature and screen visual angle (viewing distance). Data are the mean with ±1 standard deviation for 20 college students.

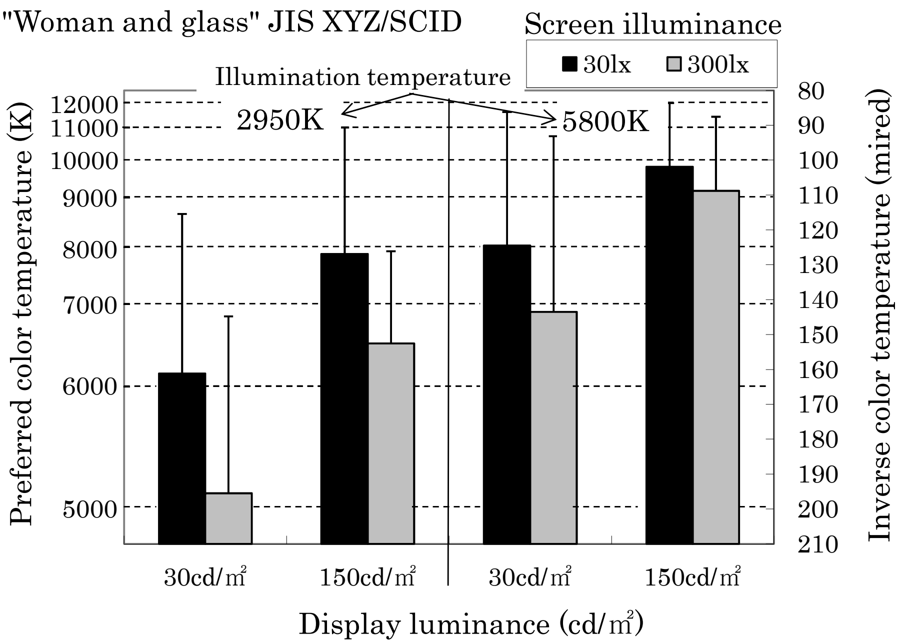


Figure 18. White point preferred color temperature by display luminance and screen illuminance. Image used is "Woman and glass" JIS XYZ/SCID.
Data are the mean with standard deviation for 20 college students.

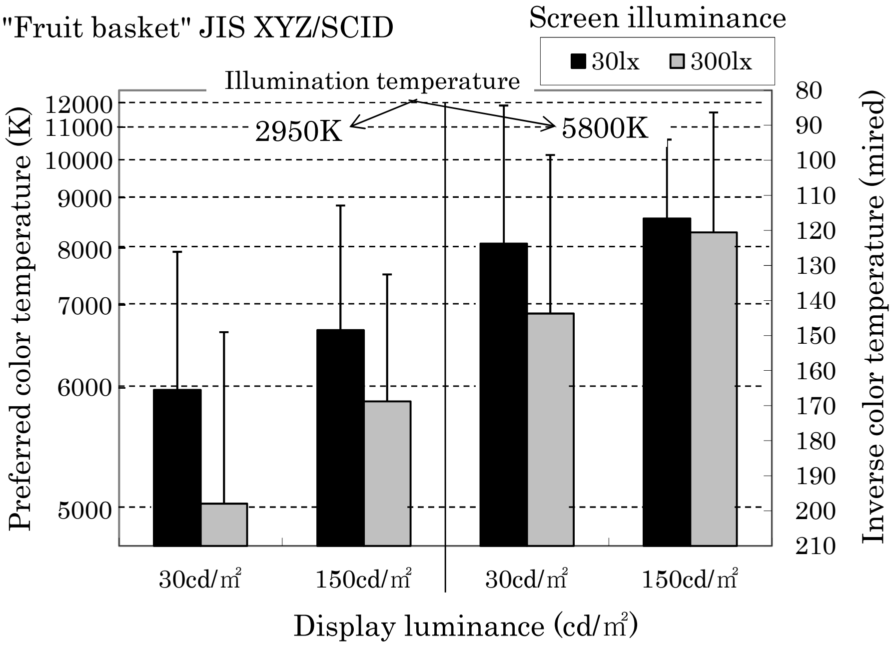


Figure 19. White point preferred color temperature by display luminance and screen illuminance. Image used is “Fruit basket” JIS XYZ/SCID.
Data are the mean with standard deviation for 20 college students.

(2) Effects of aging

Aging also affects preferred color temperature[33), 34)]. The change is not a simple shift in color temperature preference that advances with age, however; preferences shift according to the degree of yellowing of the field of vision (due to cataract formation). Figure 20 shows the results of two contrasting experiments with 20 elderly participants aged 63–79 (average age 71, artificial lens recipients not included)[33)]. In the first experiment, an image with fixed color temperature was displayed and the preferred display luminance determined using the adjustment method. In the second experiment, paired displays were used to display images at 5000 K, 6500 K, and 9300 K and the same luminance, and Scheffe’s pairwise comparison test was used to evaluate preferences. Figure 20 shows, for each participant, the obtained preferred display luminance values on the horizontal axis, and the results of the color temperature evaluation test on the vertical axis.

Participants who preferred high luminance also preferred relatively high color temperatures, and those who preferred low luminance tended to prefer low color temperatures. No such trend was seen in similar testing on young participants. This suggests that older participants who preferred high luminance have experienced advanced field of vision yellowing (cataract development), and that this yellowing results in a preference for higher color temperatures. In the future, when designing and developing television screens, display engineers will increasingly need to take into consideration such individual differences in the effects of aging.

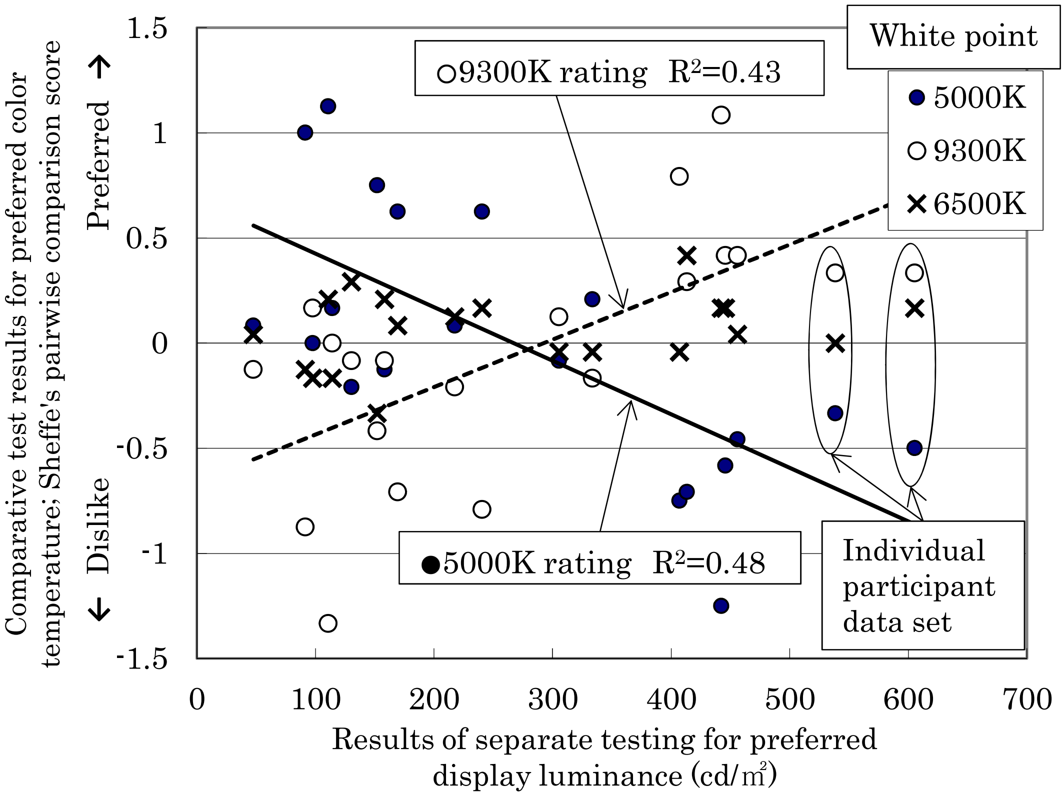


Figure 20. Test results for preferred display luminance at fixed color temperature (horizontal axis) and paired comparison testing for preference using displays with varying color temperature (vertical axis). Results are from a combination of two tests with 20 participants, aged 63–79 (mean age 71).

9. Viewing distance

The standard viewing distance for an HDTV set is 3H (three times the height of the screen), the distance at which individual pixels are no longer visible to a viewer with normal vision. This standard viewing distance, however, is not necessarily the same as the viewer's preferred viewing distance, which comes from the distance at which a feeling of presence occurs and scan lines are not discernable when viewing a static image[1)–6)]. When determining the viewing distance for televisions in general residences, the preferred viewing distance should be used as the optimum viewing distance[21)], as viewing television from within an appropriate range is necessary for reducing visual discomfort[9)]. The optimum viewing distance is influenced by both the television's screen size and display luminance[16), 17), 21), 35)–37)], but screen size is the dominant factor[21), 35)–37)].

Figures 21 and 22 show the optimum viewing distance and minimum acceptable viewing distance for various screen sizes[21)]. Figure 21 shows viewing distances in actual dimensions, while Figure 22 shows viewing distances as a multiple of screen height (H). Note that given screen sizes are in the range 24–65 in., and display luminance is assumed to be 200 cd/m^2. Mean values and ±1 standard deviations are given for each case. Table 4 gives the information in Figures 21 and 22 as actual values. Before selecting a screen size, viewers should consider the available space in the room in which the television will be placed to ensure that a sufficient viewing distance is available.

Figure 23 shows actual viewing distances for households with flat panel televisions. Almost no homes with relatively large screens had sufficient space for viewing from a 3H distance. Also of note is that in many homes, viewing occurs from beyond the optimum distance.

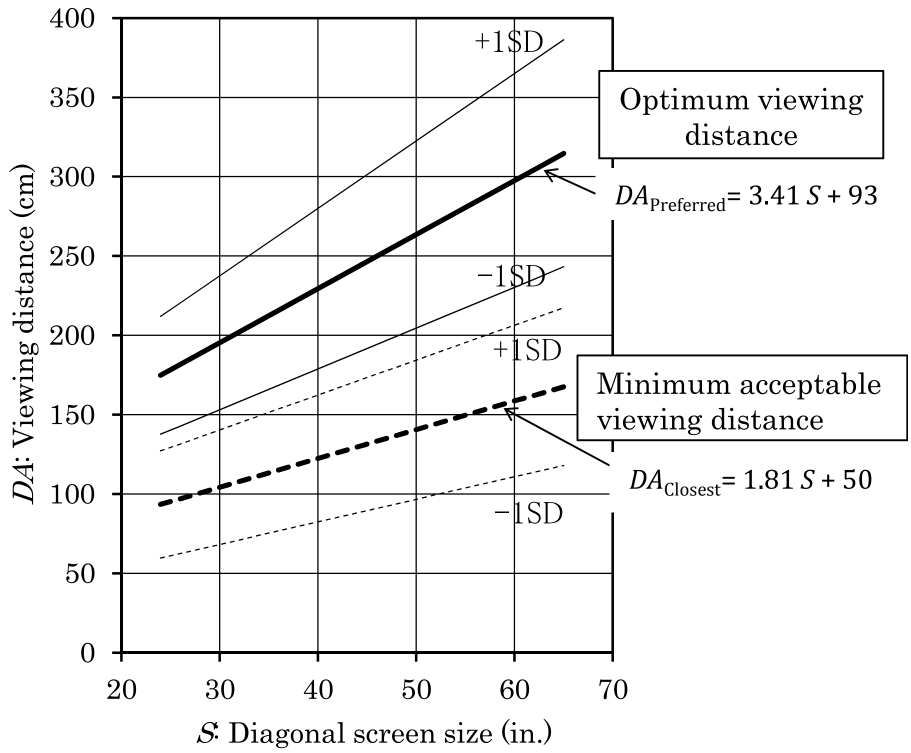


Figure 21. Optimum viewing distance (cm) and minimum acceptable viewing distance (cm) for various screen sizes. Means and ±1 standard deviations (SD) for 27 participants are given for each case.

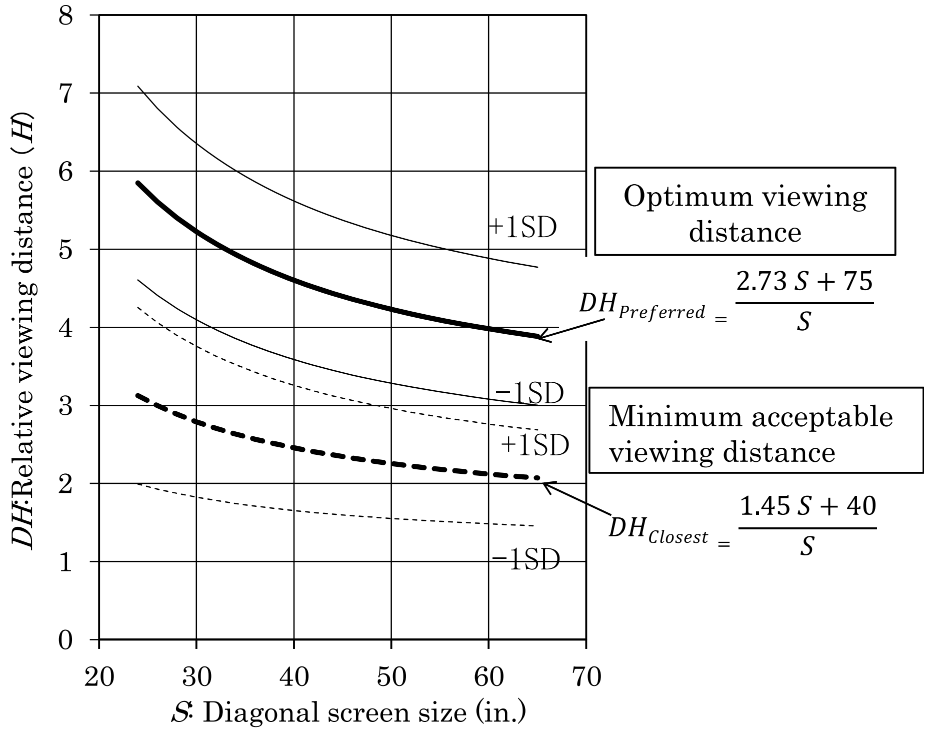


Figure 22. Optimum viewing distance (H: multiple of screen height) and minimum acceptable viewing distance (H) for various screen sizes. Means and ±1 standard deviations (SD) for 27 participants are given for each case.

Table 4. Optimum viewing distance and minimum acceptable viewing distance. Means and ±1 standard deviations (SD) are given for optimum viewing distance. Approximately 68% of participants fall within ±1 SD.

Diagonal screen size (in.)	Optimum viewing distance						Minimum acceptable viewing distance	
	cm			H			cm	H
	-1SD	Mean	+1SD	-1SD	Mean	+1SD	Mean	Mean
24	138	175	212	4.60	5.85	7.09	93.4	3.13
26	143	182	220	4.41	5.61	6.81	97.1	3.00
32	158	202	246	3.97	5.07	6.17	107.9	2.71
37	171	219	267	3.71	4.75	5.80	117.0	2.54
40	179	229	280	3.59	4.60	5.62	122.4	2.46
42	184	236	288	3.52	4.51	5.51	126.0	2.41
46	194	250	305	3.39	4.36	5.33	133.3	2.33
50	205	264	322	3.28	4.23	5.18	140.5	2.26
52	210	270	331	3.24	4.17	5.11	144.1	2.22
55	217	281	344	3.17	4.09	5.02	149.6	2.18
58	225	291	356	3.12	4.02	4.93	155.0	2.14
60	230	298	365	3.08	3.98	4.88	158.6	2.12
65	243	315	386	3.00	3.89	4.77	167.7	2.07

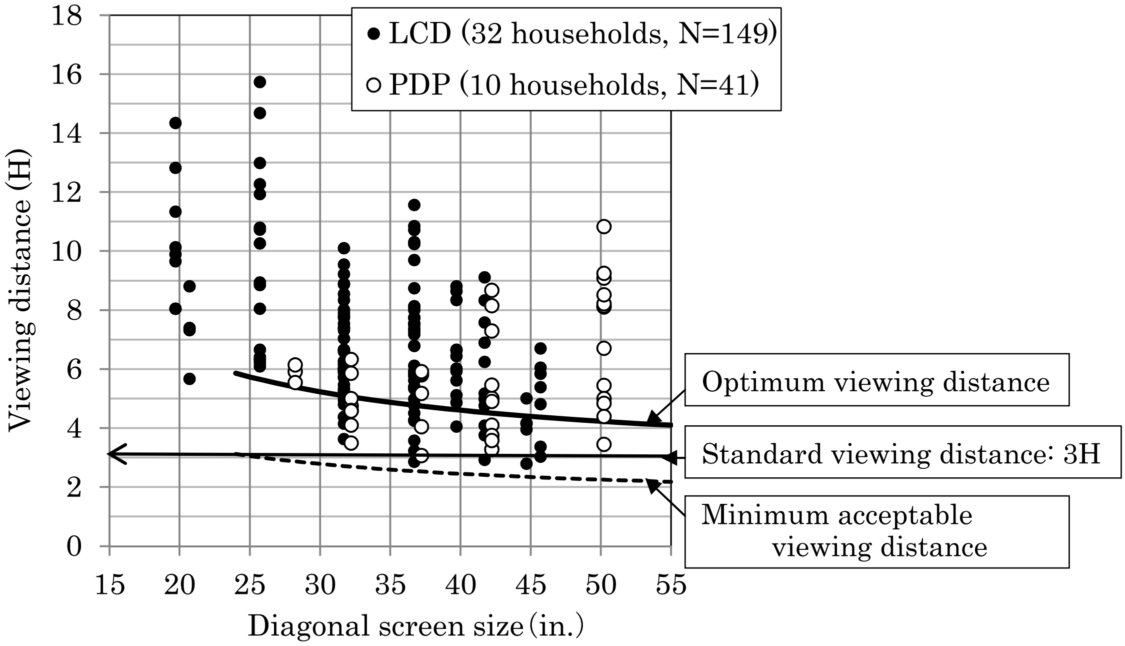


Figure 23. Screen size and viewing distance (H) for homes with flat panel televisions. Values are for 16:9 aspect ratio LCD and plasma televisions only (CRT-based televisions are excluded). The graph shows experimentally determined values for both optimum viewing distance and minimum acceptable viewing distance.

10. Display height

General guidelines for the optimum height for a television screen differ from those for computer monitors. The best height for a computer monitor is generally taken to be such that the top edge of the monitor is at the same height as the eyes, or slightly lower[38], but television heights should be such that the viewer's eyes are at an equal height to the center of the screen[38] (see Figure 24). This guideline does not vary with screen size or viewing distance, a finding that has been verified through both experiments and field surveys[39].

Figure 25 shows the results of preferred screen height adjustments for viewing 32-, 42-, and 65-in. televisions while sitting in chairs and on the floor. Eye height was approximately 110 cm above the floor in the former case, and 80 cm in the latter, so preferred height was equivalent to one in which eye level was even with the middle of the screen. Figure 26 shows eye height while viewing television for 393 persons in 83 households. Setting aside the case of viewing from a reclined position, televisions should be placed in accordance with these heights.

Figure 27 shows the line of sight angle for these 393 persons while looking at the center of the screen. The distribution has a mode of 0° horizontal, indicating that positioning so that the center of the screen is at eye level is the most common real-world case.

Figure 28 shows a graph of screen size and screen center height for 83 households. Screen center height was roughly 60–100 cm, and was not dependent on screen size.

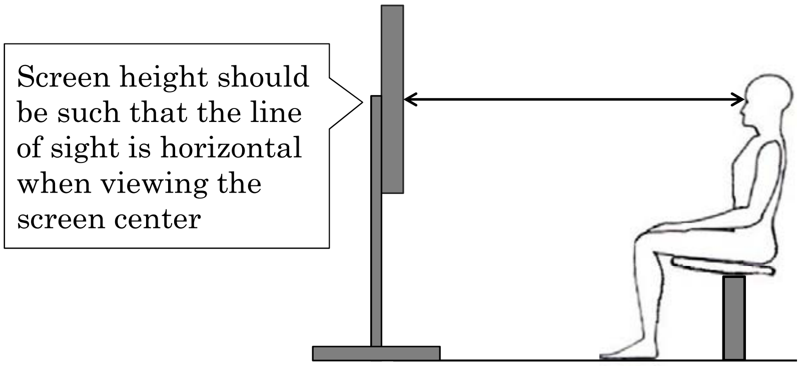


Figure 24. Optimum television screen height.

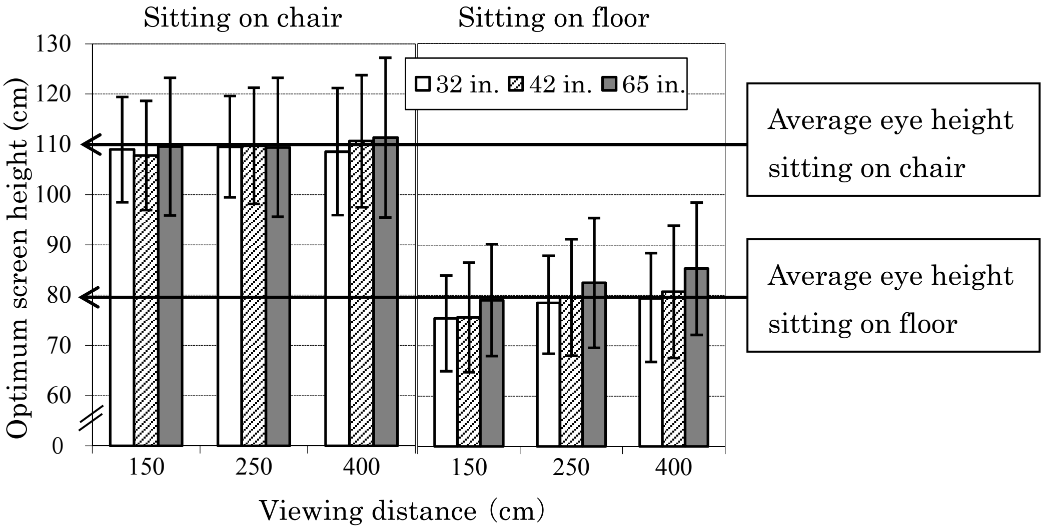


Figure 25. Optimum television screen height (from floor to screen center). Mean and ±1 standard deviations for 31 participants.

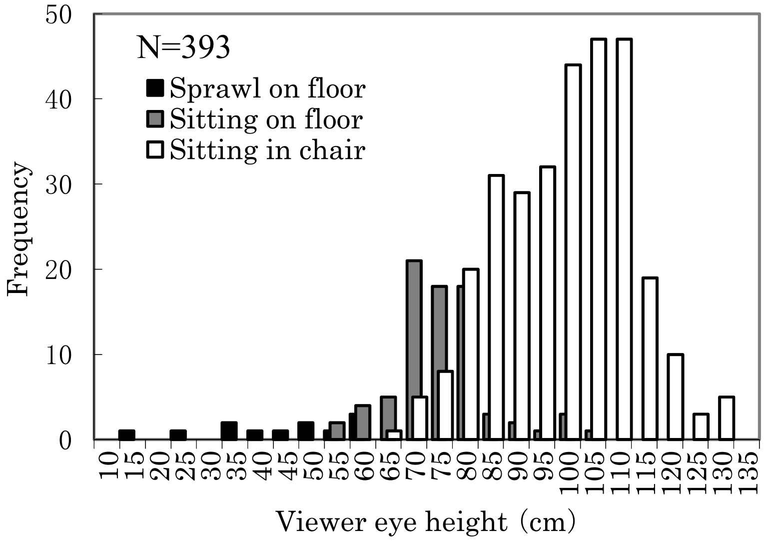


Figure 26. Actual eye height (distance from floor to eyes) while viewing television.

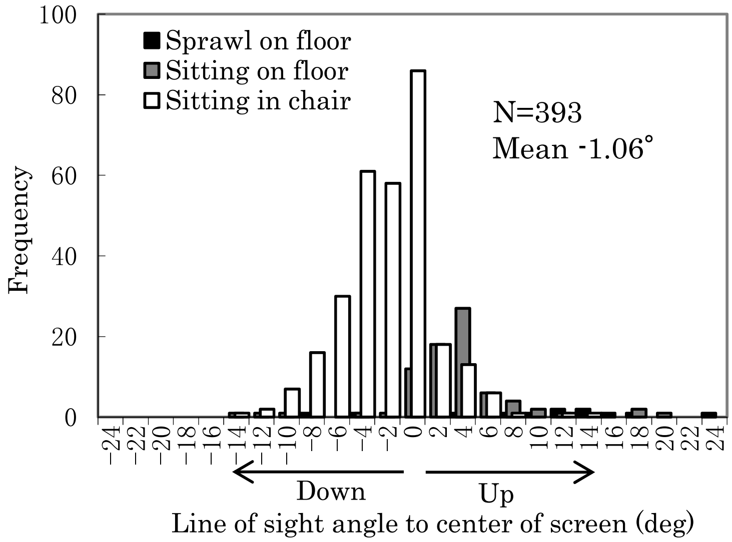


Figure 27. Line of sight angle to screen center.

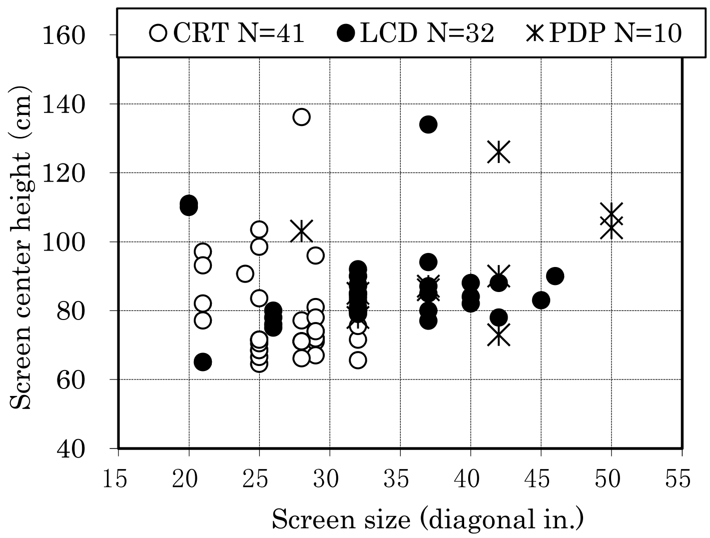


Figure 28. Television screen center height for 83 households.

11. Screen tilt angle

(1) Optimum tilt angle

We take optimum tilt angle as the most preferred vertical surface angle as determined by test participants when given a device allowing them to freely change the screen tilt angle while viewing television. Defined this way, tilting the screen so that a line drawn from the viewer's eyes the television screen center is normal to the screen does not necessarily result in the optimum tilt angle. The actual optimum tilt angle varies with the relationship between eye and screen height, as shown in Figure 29. When these heights are equal, an approximately 1.5° forward tilt was the optimum tilt angle. When the screen center height is 30 cm lower than eye height, at a 3H viewing distance the predicted optimum angle based on a screen-normal line is an 8° backward tilt, but the optimum tilt angle is actually an approximately 2° backward tilt. Conversely, when the screen center height is 30 cm above eye height, at a 3H viewing distance the predicted optimum angle based on a screen-normal line is an 8° forward tilt, but the optimum tilt angle is actually an approximately 4° forward tilt (see Figure 30). These values are based on viewing a 58-in. plasma television from a 3H viewing distance, but roughly the same values were obtained from a 5H viewing distance, indicating that within a 3–5H viewing distance range there is little influence of viewing distance on optimum tilt angle. Equation (4) gives the relationship between optimum screen tilt angle and screen center height for a 3–5H viewing distance:

$$\Theta = 0.10\ h + 1.58 \qquad (4)$$

where the screen optimum tilt angle θ (deg) is positive for a forward tilt, and negative for a backwards tilt, h (cm) is the relative screen center height with eye height taken as 0, and $-40 \leq h \leq 40$.

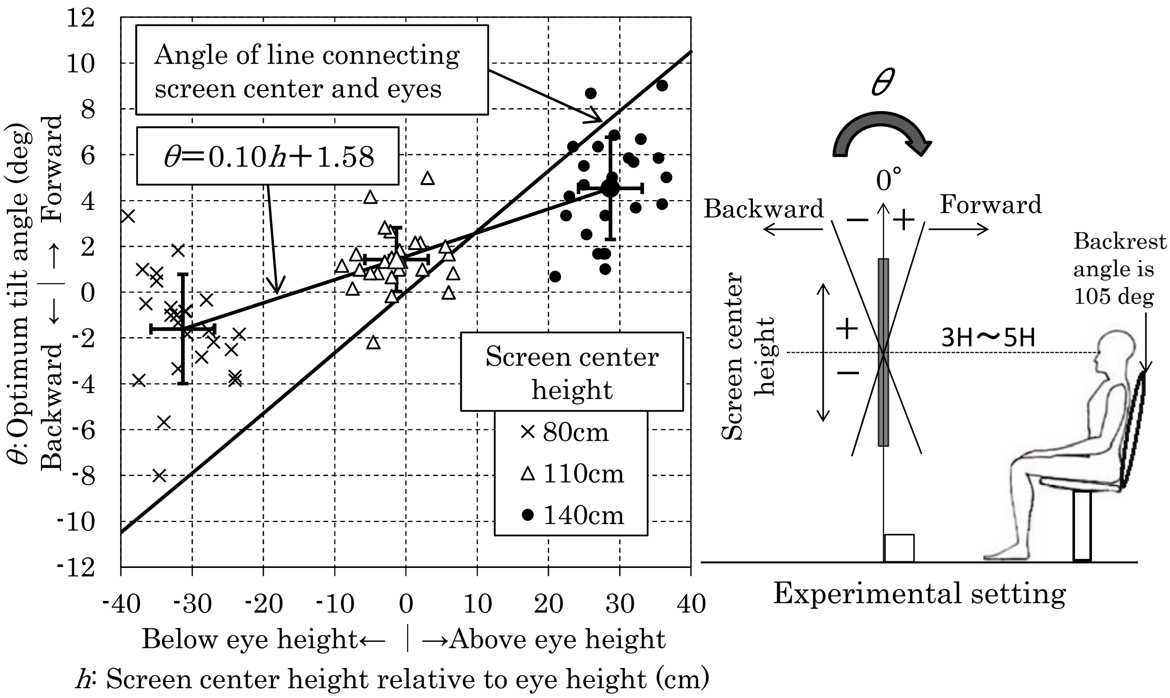


Figure 29. Optimum tilt angle of TV screen as a function of screen center height. Data from 25 participants.

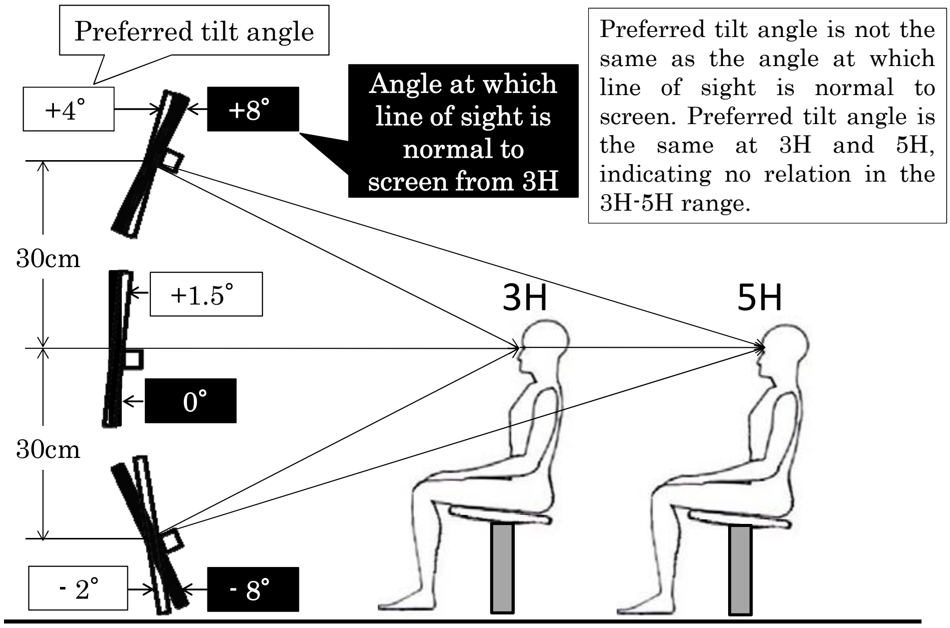


Figure 30. Screen height and screen optimum tilt angle.

(2) Minimize screen glare by tilting screen

For large-screen televisions, changing the screen tilt is a common way to avoid glare from reflected lighting fixtures. Figure 31 shows a distribution of lighting fixture reflections on television screens, based on a television viewing environment survey of 83 households[40]. The figure uses the relationship between television screen placement, lighting fixture placement, and viewer eye position to show where lighting fixtures would be reflected, causing glare, if screen size were increased. Plots assume a vertical screen surface.

Figure 32 shows the probability that lighting fixtures will be reflected on various sizes of television screens, based on the results of Figure 31. In other words, the figure shows the probability that lighting fixtures will be reflected in field living rooms when the display height is changed for different screen sizes. As the screen size or height increases, the probability that lighting fixtures will be reflected also increases. Even for a 50-in. television, if the height of the screen's lower edge is 70 cm, lighting fixtures will be reflected, causing glare, in close to 10% of households.

Figure 33 shows lighting fixture reflection angle distributions, divided into vertical and horizontal directional components. Taking the vertical components, most reflections are in the range 8–15° normal to the screen surface, indicating that reflection avoidance can be realized with a relatively shallow cutoff angle for lighting fixture shielding.

Tilting the screen forward can also lower the probability of light fixture reflection. Figure 34 shows the effects of reflection reduction through forward screen tilting, and indicates that a forward tilt of 5° reduces the probability of lighting fixture reflection by roughly half. The remaining problem is to what extent the screen can be tilted before interfering with image viewing. Figure 35 shows extents to which viewers find screen tilt annoying, and indicates that when screen height is at eye level a screen tilt of up to around 5° is permissible. Forward screen tilting within this range is therefore a useful method for avoiding lighting fixture reflection.

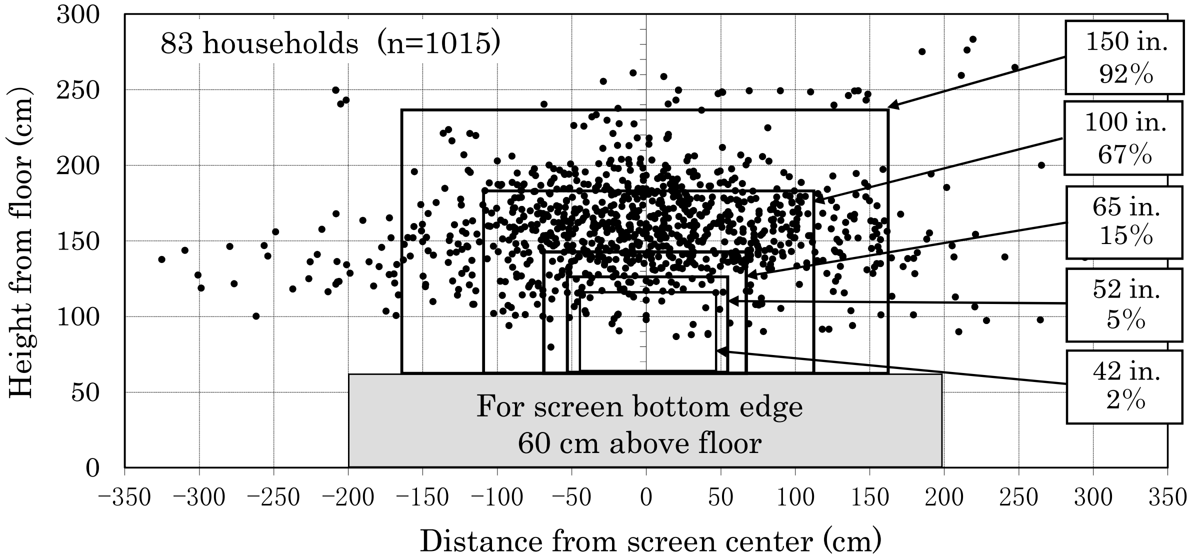


Figure 31. Distribution of lighting fixture reflections, overlaid with various television screen sizes with bottom edge 60 cm above floor.

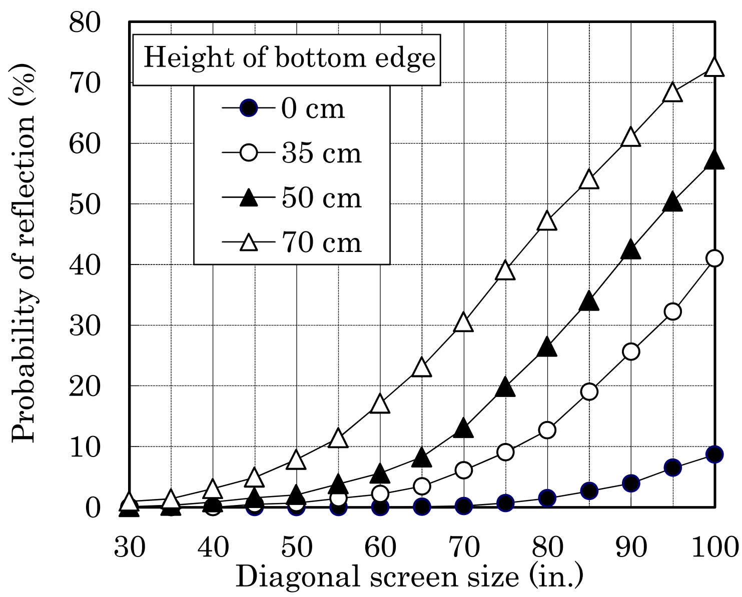


Figure 32. Probability of lighting fixture reflection by screen size and height for living rooms of 83 households.

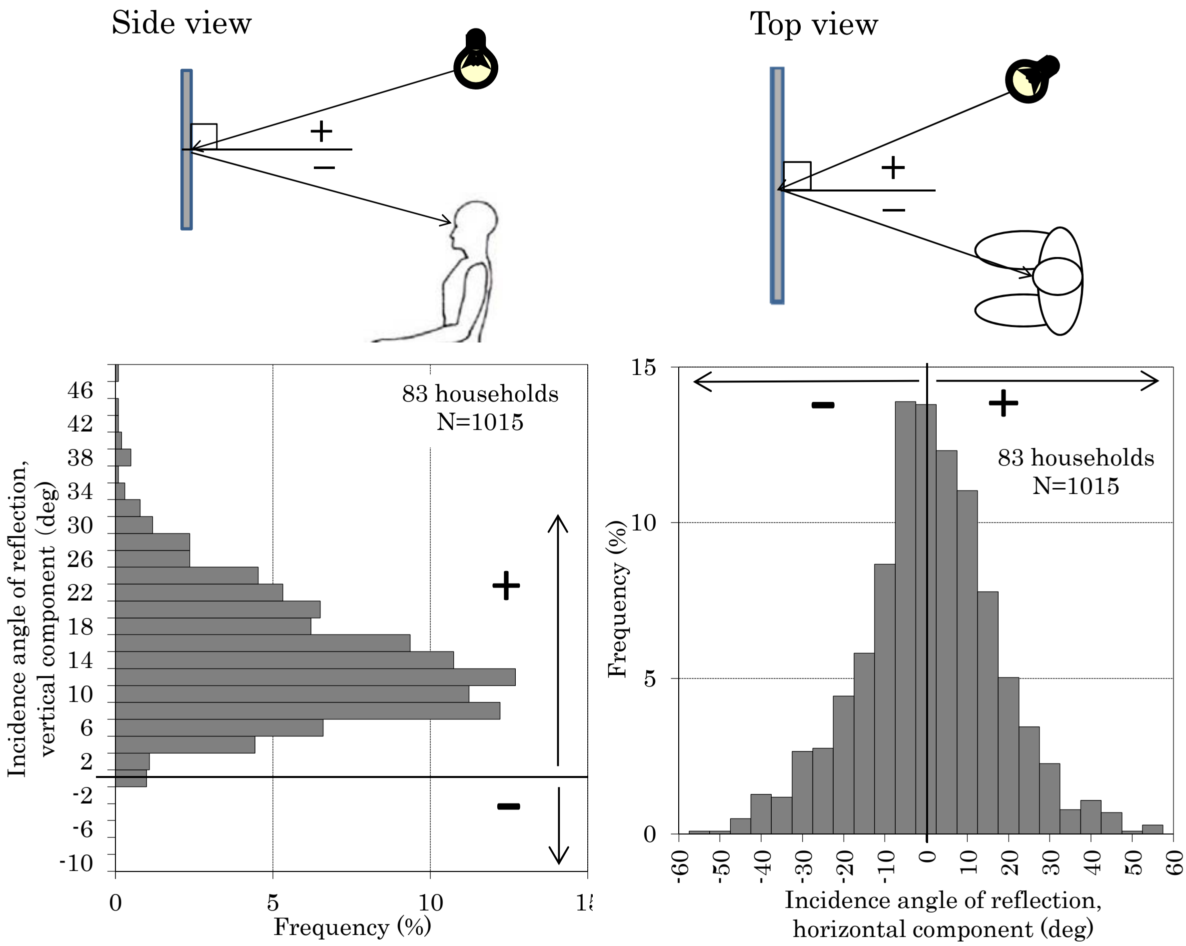


Figure 33. Distribution of illumination fixture reflections on television screens in 83 households.

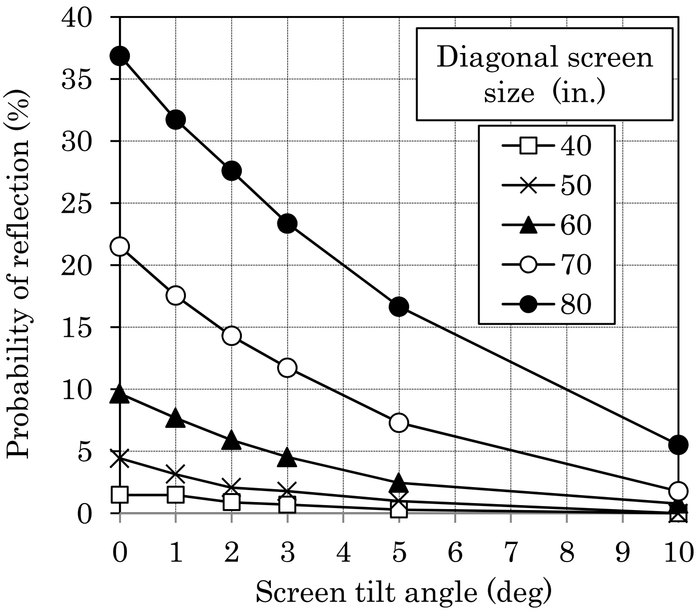
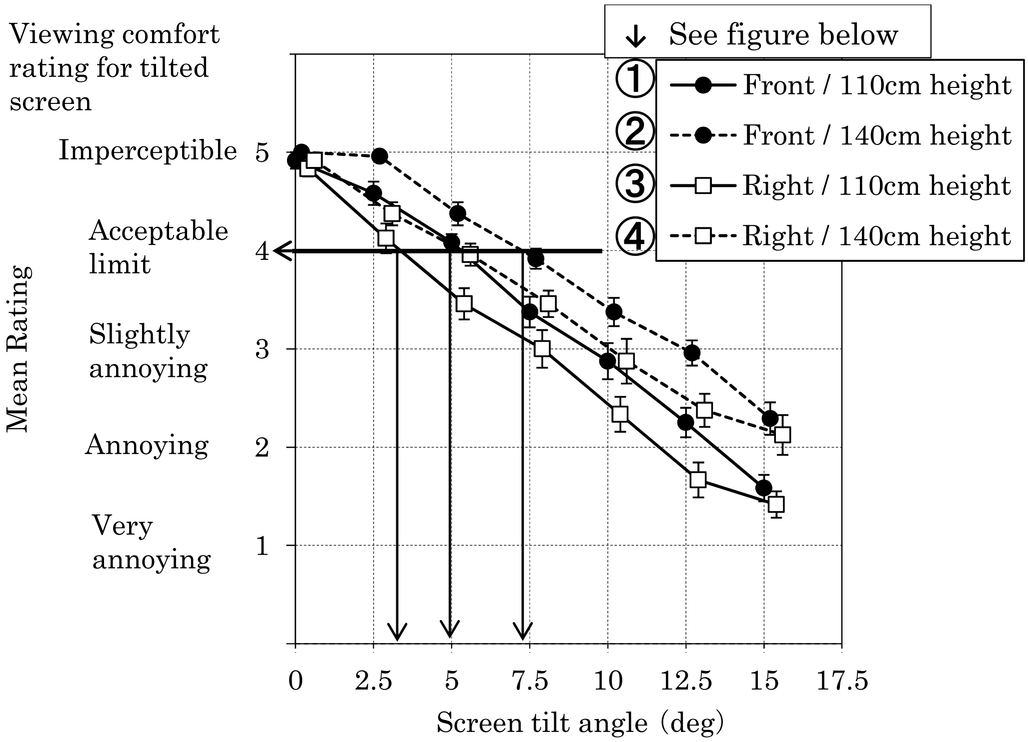


Figure 34. Reduction of illumination fixture reflection through tilting the screen forward. Bottom edge of screen is assumed to be 60 cm above floor.



Graphs are results for television viewing in the four situations shown below:

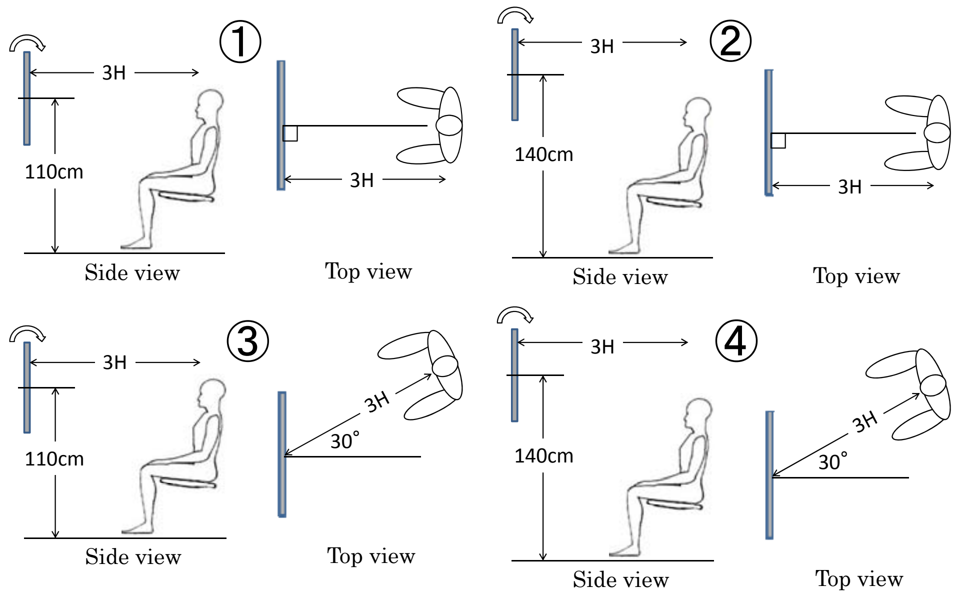


Figure 35. Relationship between screen tilt angle and degree of annoyance. Mean and ±1 standard deviation for 24 viewers at a 3H viewing distance.

12. Viewing angle

No display can avoid the differences in display characteristics such as display luminance, contrast, and chromaticity that arise from varying the viewing angle. Under actual viewing conditions, however, such differences are not a problem as long as such changes are less than perceptible limits, or at least within acceptable limits. It is therefore necessary to establish what range of viewing angles allows for television viewing in actual homes. Restricting changes in display characteristics in that range to within acceptable levels will thus be a goal for ergonomic design and development.

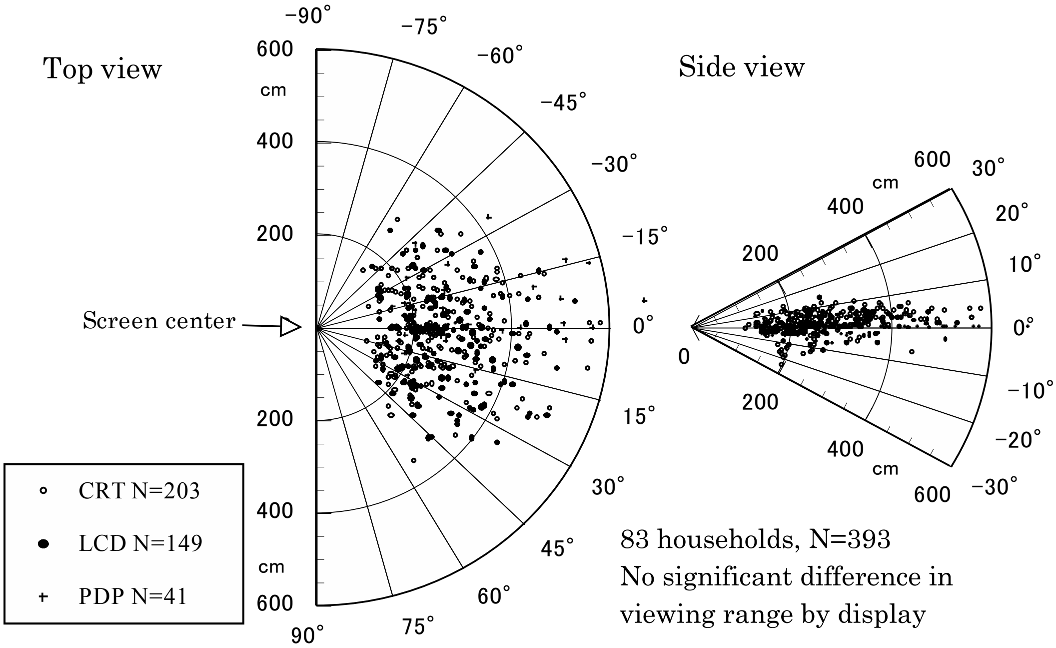


Figure 36. Viewing positions for 393 locations in 83 households.

Figure 36 shows a graph of eye positions with respect to television screen centers during television viewing from 393 locations in 83 household living rooms. Data were obtained during a survey conducted between 2007 and 2008[8), 19)]. No significant difference according to display technology or screen size was indicated. As described above, actual viewing positions are largely determined by furniture placement and room size.

Figure 37 shows a distribution of the absolute value of viewing angles normal to screen center, split into horizontal and vertical components, for which 95th percentile values are 40° horizontal and 10° vertical. Results obtained in television viewing position surveys conducted in 2004[22)] and 2005[25)] are roughly the same as these values, despite different ratios of screen size and display technology between those years. These results also agree with experimental tests performed to find tolerable horizontal viewing angle ranges for LCD screens[41)]. Therefore, to satisfy 95% of viewers in terms of viewing angle characteristics, such changes must be held to within imperceptible or tolerable ranges for viewing angles of ±40° horizontally, and ±10° vertically. Note, however, that the discussion so far extends only to viewing domains based on the screen center, but, as shown by Figure 38 and Equation (5) therein, the viewing angle in actual television viewing is greatest for far side edges, so screen size must also be taken into consideration[42].

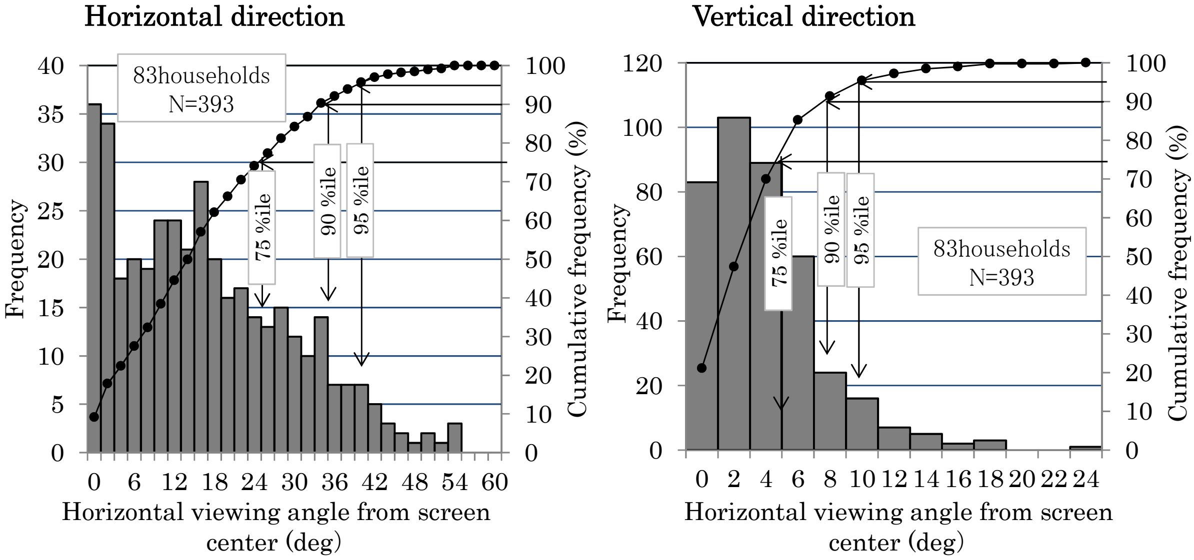
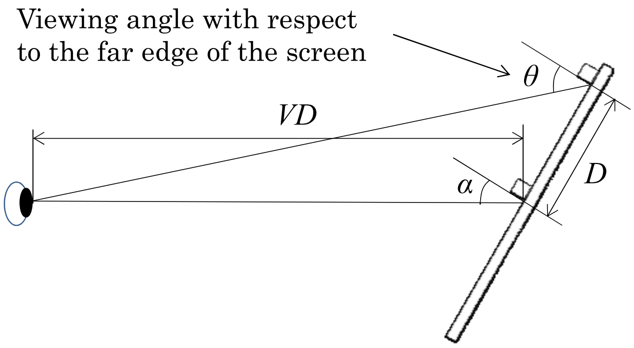


Figure 37: Viewing angle distributions, normal to screen center.
Left: horizontal direction. Right: Vertical direction.



$$\theta = \tan^{-1}\frac{D\sin(90-|\alpha|)}{VD + D\cos(90-|\alpha|)} + |\alpha| \quad \cdots\cdots(5)$$

θ: Viewing angle with respect to the far edge of the screen (deg)

VD: Viewing distance (cm)

α : Viewing angle to the center of the screen (deg)

D : Distance from screen center to the edge (cm)

Figure 38. Difference in viewing angles for screen center and screen edge.

Figures 39 and 40 respectively show distributions of viewing angles for screen far side edges (farthest points) of 32-in. and 55-in. screens, divided into horizontal and vertical direction components. For the 32-in. screen horizontal angle (Figure 39, left) the 95th percentile value is 46°, and that for the 55-in. screen (Figure 40, left) is 50°, both of course larger than the screen center value of 40°. The vertical values are 17° for the 32-in. screen (Figure 39, right) and 21° for the 55-in. screen (Figure 40, right). It is therefore necessary to design screens, LCDs in particular, so that changes in display characteristics within these ranges are within imperceptible or at least tolerable levels.

Table 5 shows 95th percentile, 90th percentile, 3rd quartile, and 75th percentile values for a variety of screen sizes from 24 to 65 in. for analyses similar to those of Figures 39 and 40. Keeping image display changes to an imperceptible level for the given ranges will result in the applicable percentage of viewers viewing the television without noticing any change in display characteristics due to viewing angle. As these results indicate, it is necessary to sufficiently take screen size into account when designing viewing angle characteristics.

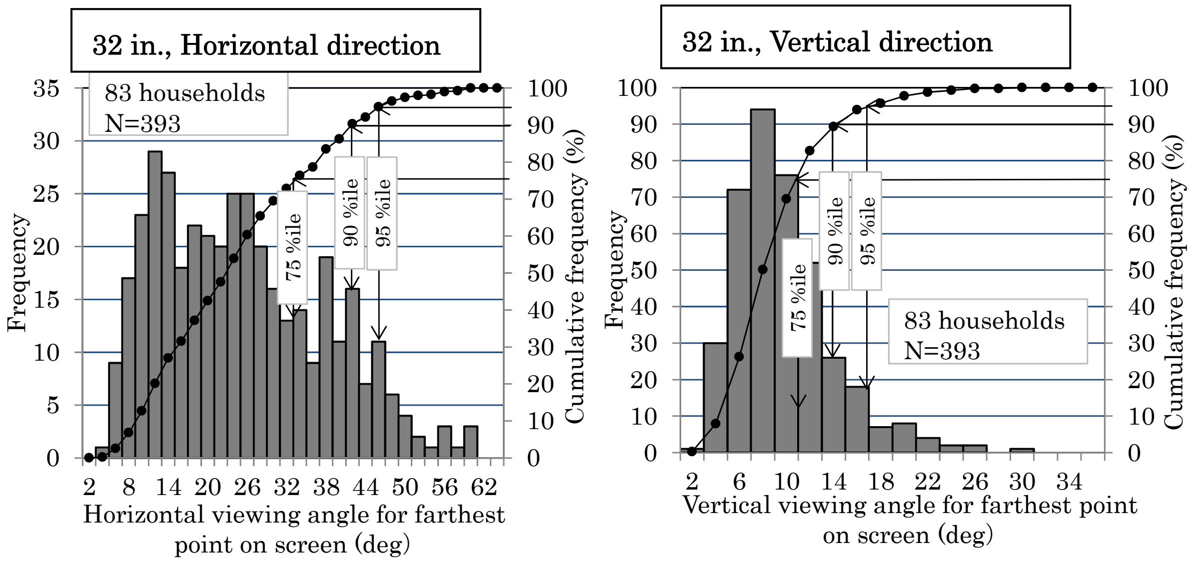


Figure 39. Viewing angles for farthest point on a 32-in. screen.
Left: horizontal direction. Right: vertical direction.

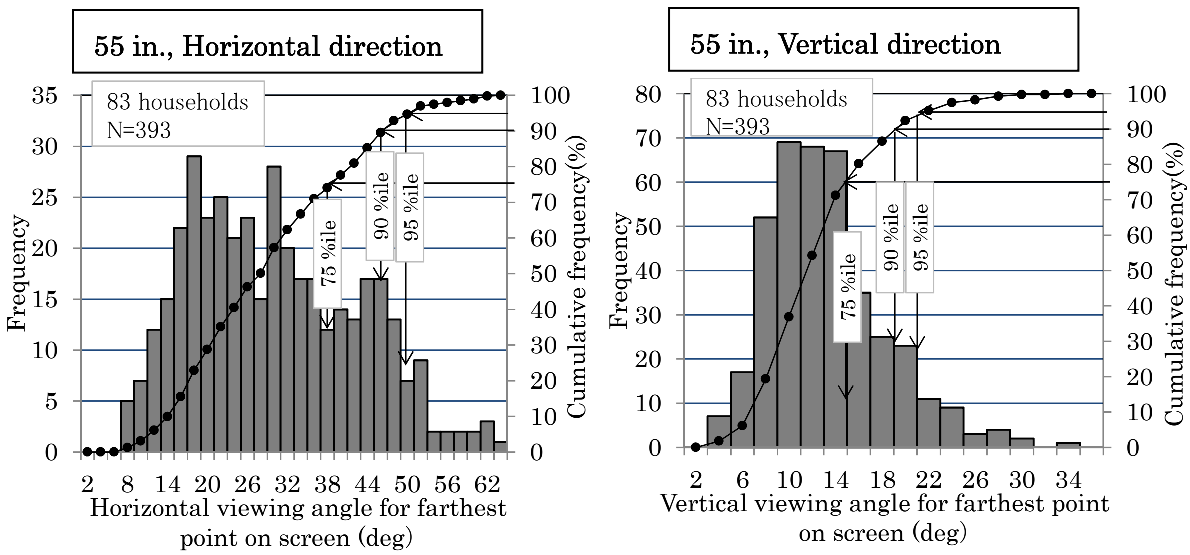


Figure 40. Viewing angles for farthest point on a 55-in. screen.
Left: horizontal direction. Right: vertical direction.

Table 5. Actual television viewing angles for screen center and farthest screen point at various screen sizes, with percentile values.

Percentile	Direction	Viewing angle with respect to screen center	Viewing angle with respect to screen's farthest point at various sizes				
			Diagonal screen size (in.)				
			24	32	42	55	65
95th	Horizontal	40	45	46	48	50	52
	Vertical	10	15	17	19	21	24
90th	Horizontal	35	40	42	44	46	48
	Vertical	7	13	14	16	19	21
75th	Horizontal	25	32	33	35	38	40
	Vertical	5	9	11	13	15	17

Unit: deg

13. Conclusions

These Guidelines use real-world viewing of flat panel display televisions and multifaceted laboratory testing to summarize principles that should be taken into consideration in the ergonomic design and development of televisions that can most comfortably be viewed under real-world environments and usage conditions. These Guidelines were created with the goal of allowing engineers involved in many aspects of television technology to incorporate such factors into their designs as viewing environment and conditions, individual differences due to age and other causes, and differences in displayed images. Please note that the optimum values given for the various design factors discussed here are optimal developmental goals strictly from the standpoint of ergonomics, and should be pursued only to the extent possible within the scope of other product development constraints.

Developing new displays that better suit the display characteristics for a wide variety of viewers and viewing conditions will result in more comfortable viewing, while consuming less energy. To that end, we hope that these Guidelines will be useful to a wide variety of television engineers.

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Annex

Results of Web questionnaire survey on viewing conditions of
LCD televisions at home

\- A comparison of six countries -

(Brazil, China, India, Japan, the United Kingdom, and the United States)

Results of Web questionnaire survey on viewing conditions of LCD televisions at home

- A comparison of six countries -

(Brazil , China , India , Japan ,
the United Kingdom , the United States )

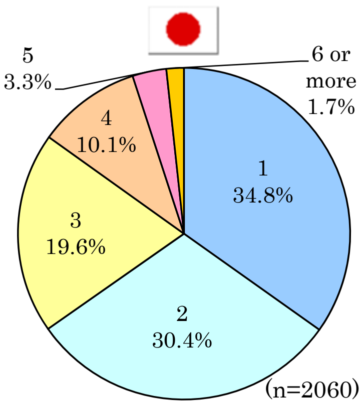
Country	Survey period	Number of samples
	2011／7／20－7／21	2,060
	2011／7／13－7／27	1,000
	2009／7／28－8／16	580

The number of samples for each category

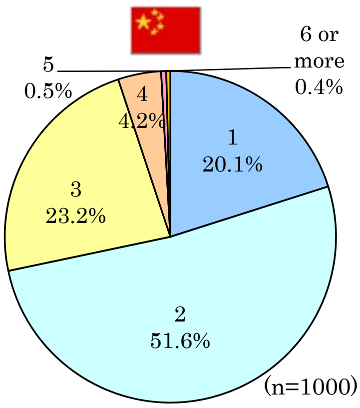
		Japan	China	India	Brazil	The United Kingdom	The United States
Gender and age							
Male	20s	206	120	115	100	58	58
	30s	206	120	115	100	58	58
	40s	206	104	107	100	58	58
	50s	206	109	109	100	58	58
	60s or more	206	47	54	100	58	58
	Sub total	**1030**	**500**	**500**	**500**	**290**	**290**
Female	20s	206	130	162	100	58	58
	30s	206	130	162	100	58	58
	40s	206	115	130	100	58	58
	50s	206	104	40	100	58	58
	60s or more	206	21	6	100	58	58
	Sub total	**1030**	**500**	**500**	**500**	**290**	**290**
Total		**2060**	**1000**	**1000**	**1000**	**580**	**580**

No.	Question
Q1	How many televisions do you have in your home?
Q2	Which direction(s) do the windows face?
Q3	Do you adjust the lighting when watching television?
Q4	When did you purchase the LCD television that you mainly watch in the living room with your family and such?
Q5	Have you ever made any picture quality adjustments (brightness, color, etc) on the LCD television that you mainly watch in the living room with your family and such?
Q6	What is the screen size of the LCD television that you mainly watch in the living room with your family and such?
Q7	What size television would you like to put in your living room, etc. in the future to mainly use with your family and such?
Q8	What size television could you actually fit in the room (e.g. living room) where you would put the television to be mainly watched with your family and such?
Q9	On average, how many hours a day do you spend watching television?
Q10	What is the number of people at your home who watch the television that you mainly watch in the living room with your family and such? *Please include yourself in the number. *Answer with the most frequent number of people watching television together.
Q11	What kinds of programming do you frequently watch on the television that you mainly watch in the living room with your family and such. Choose up to three.
Q12	This question concerns the LCD television that you mainly watch in the living room with your family and such. Do you use the television for anything else other than watching television?
Q13	This question concerns the television that you mainly use at home LCD. For each statement below, choose one response that best applies to you.
Q14	Which of the following features do you think are necessary?

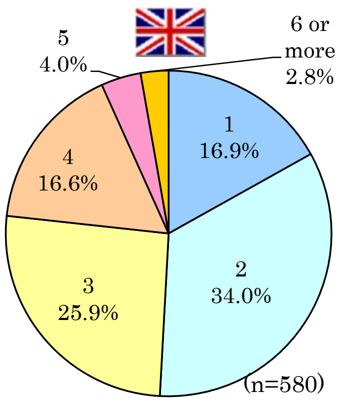
Q1:How many televisions do you have in your home?



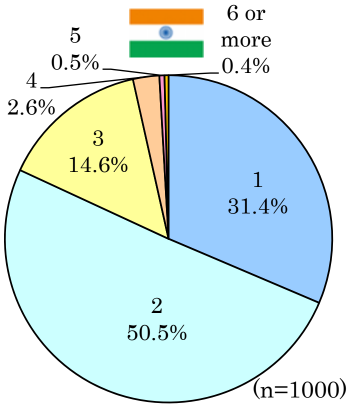
Avg:2.2 televisions



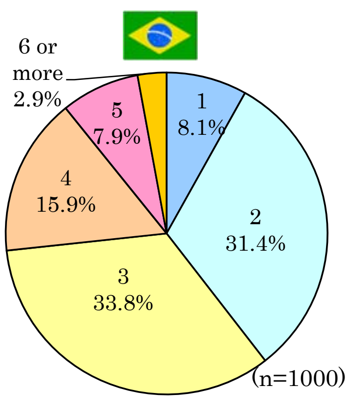
Avg:2.1 televisions



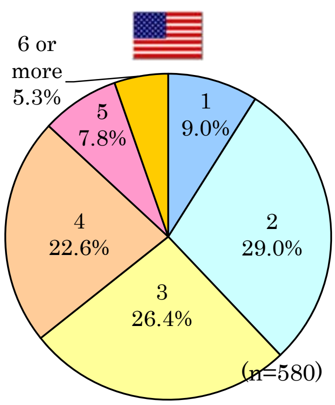
Avg:2.7 televisions



Avg:1.9 televisions

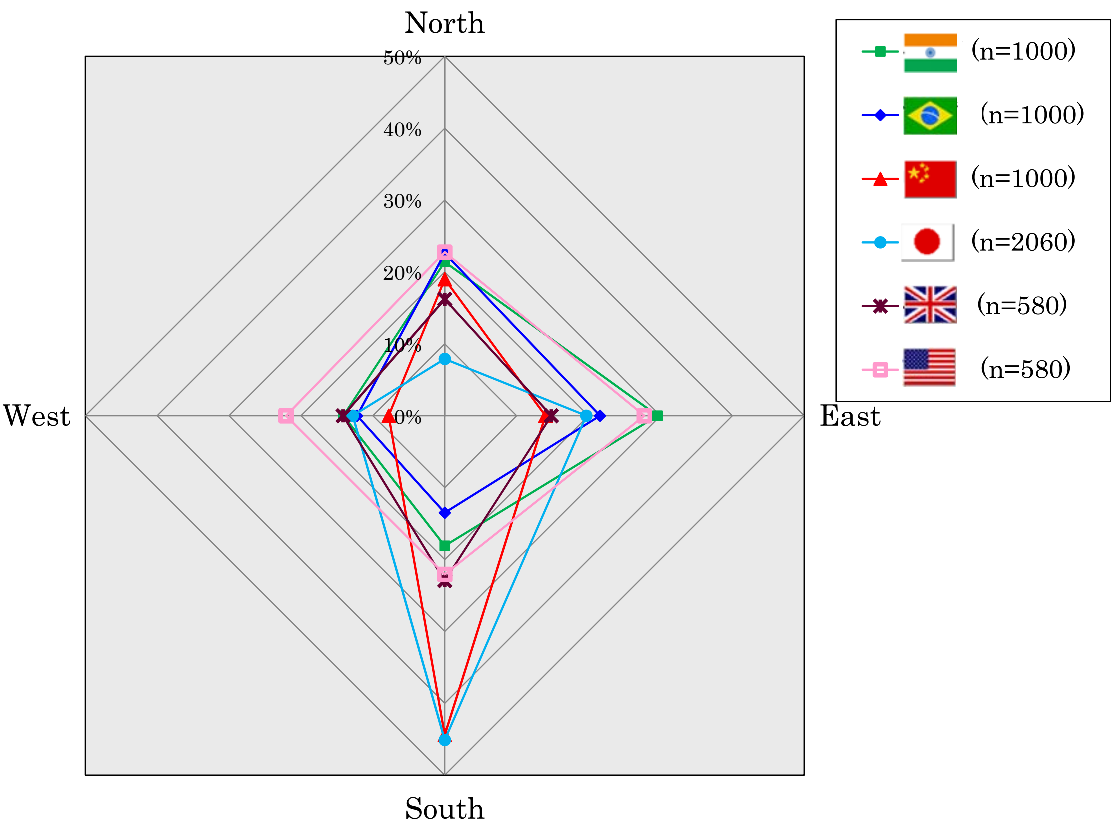


Avg:2.9 televisions

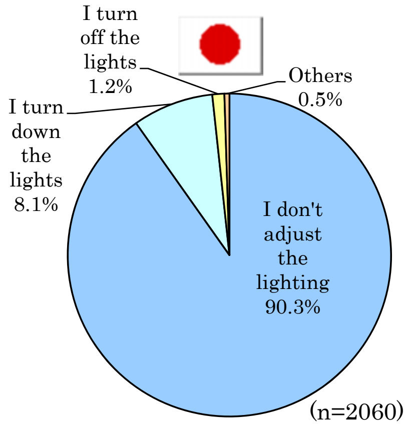


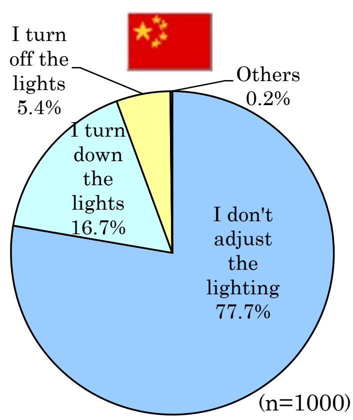
Avg:3.1 televisions

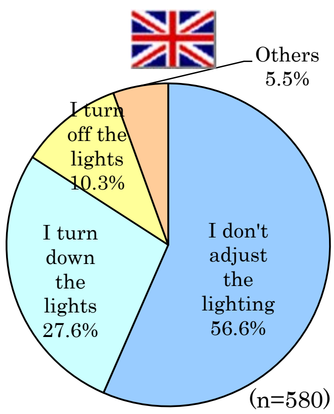
Q2: Which direction(s) do the windows face?

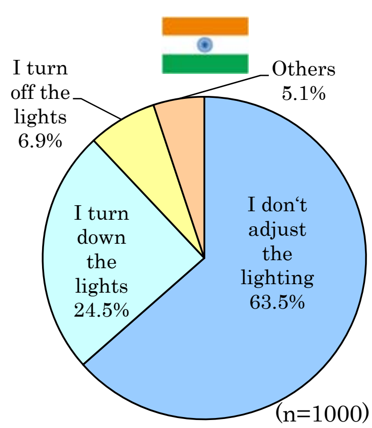


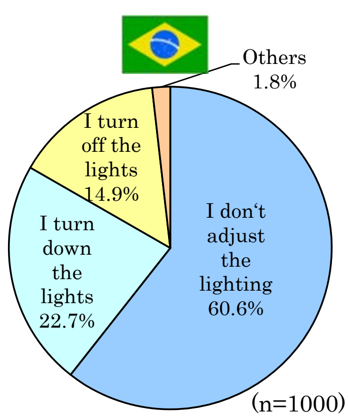
Q3: Do you adjust the lighting when watching television?

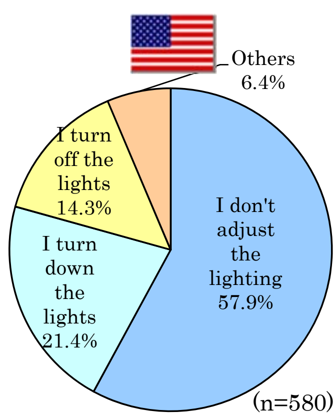




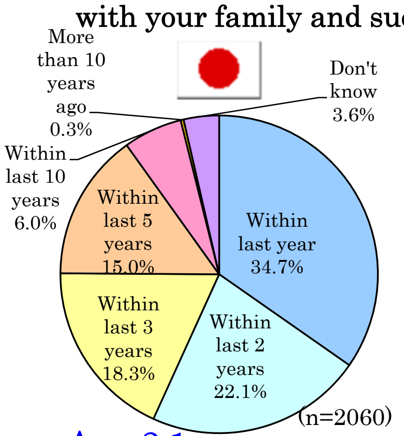




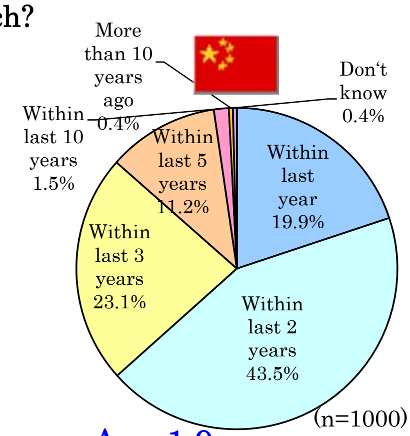




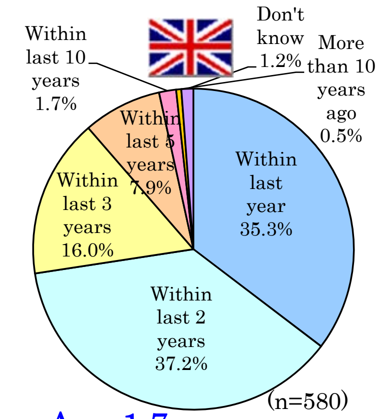
Q4: When did you purchase the LCD television that you mainly watch in the living room with your family and such?



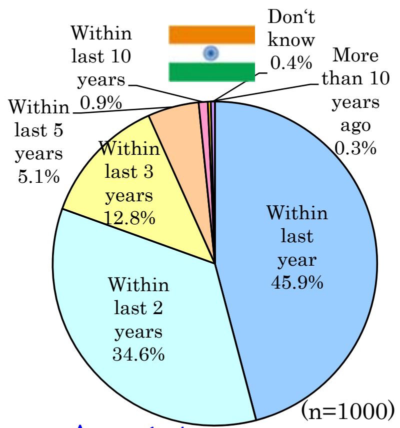
Avg: 2.1 years ago



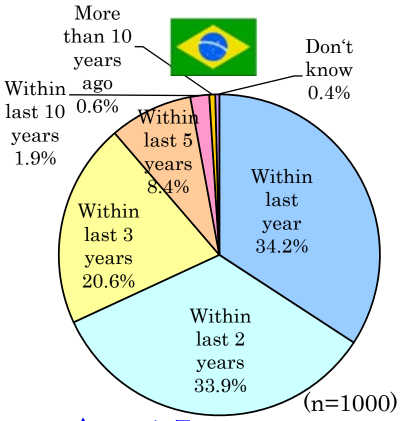
Avg: 1.9 years ago



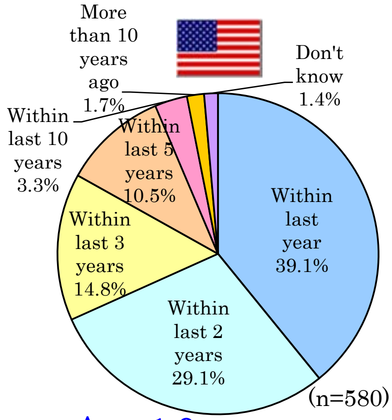
Avg: 1.7 years ago



Avg: 1.4 years ago

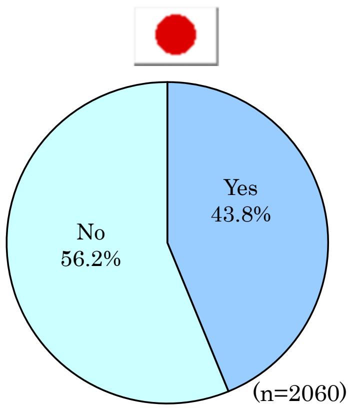


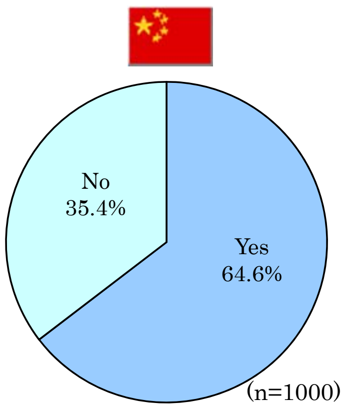
Avg: 1.7 years ago

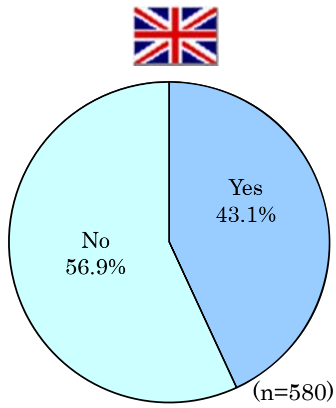


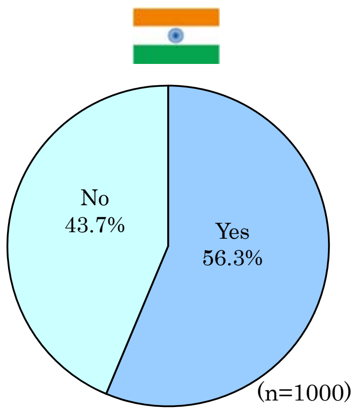
Avg: 1.9 years ago

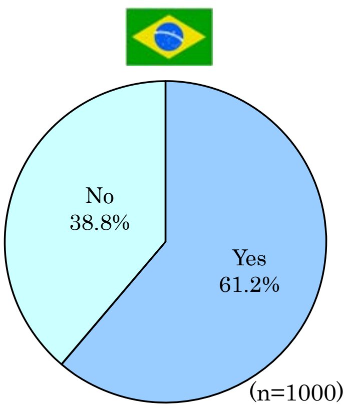
Q5: Have you ever made any picture quality adjustments (brightness, colour, etc) on the LCD television that you mainly watch in the living room with your family and such?

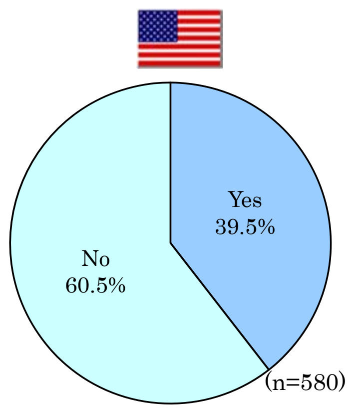




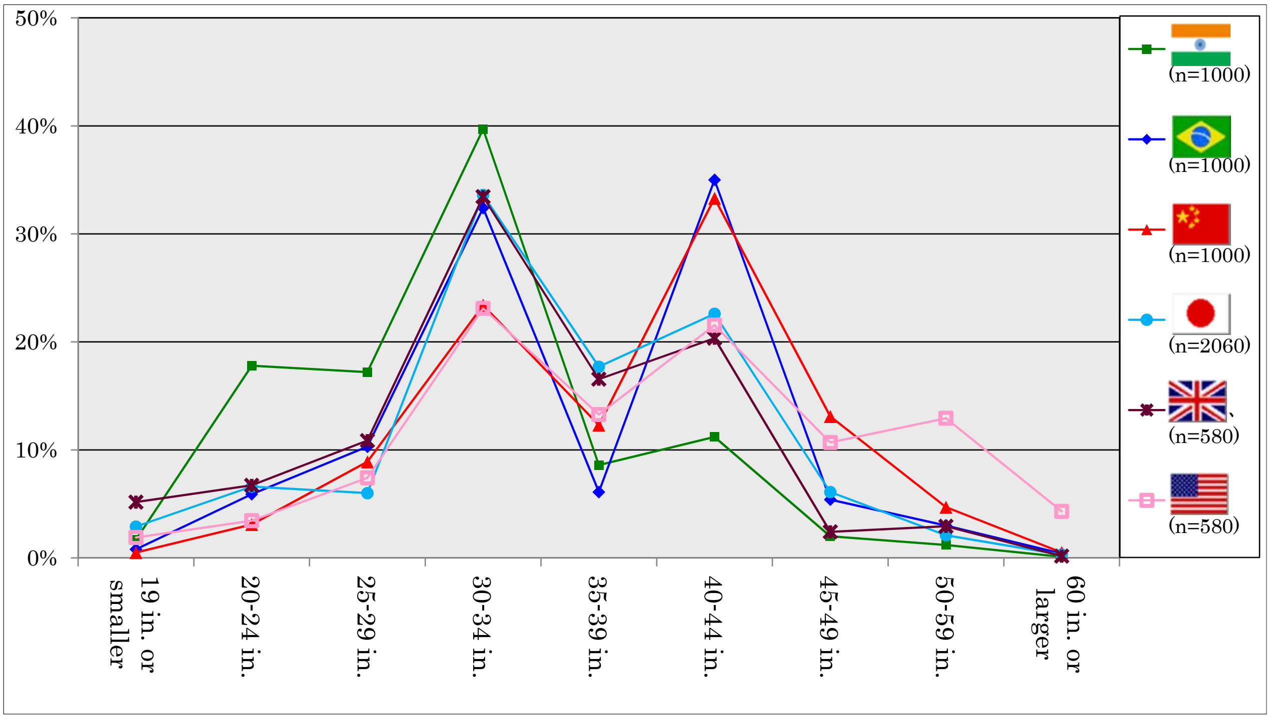


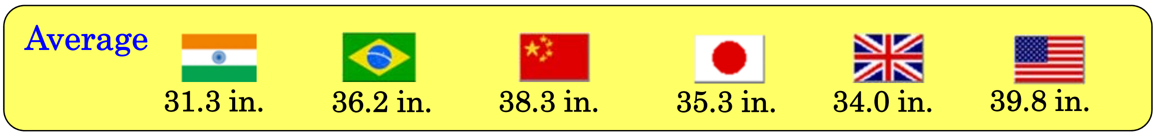




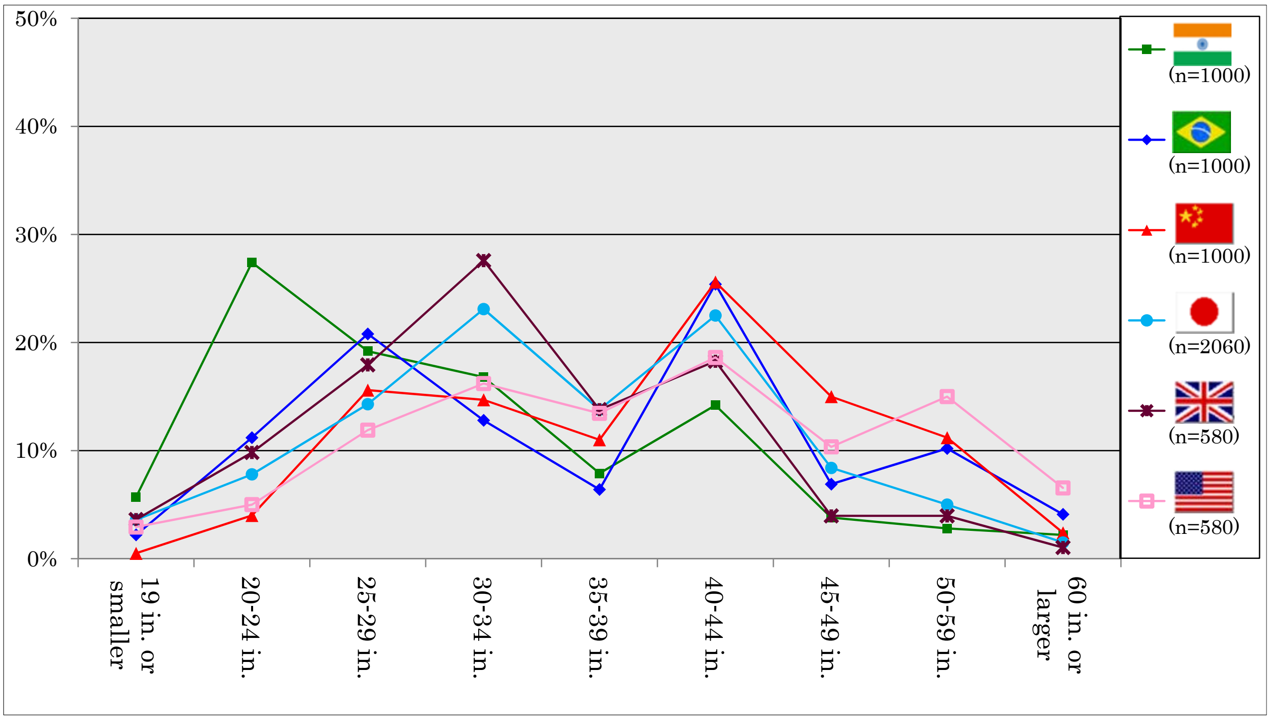


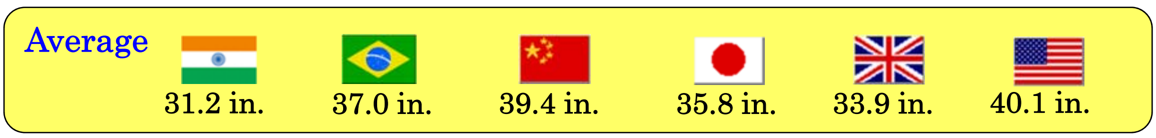
Q6: What is the screen size of the LCD television that you mainly watch in the living room with your family and such?



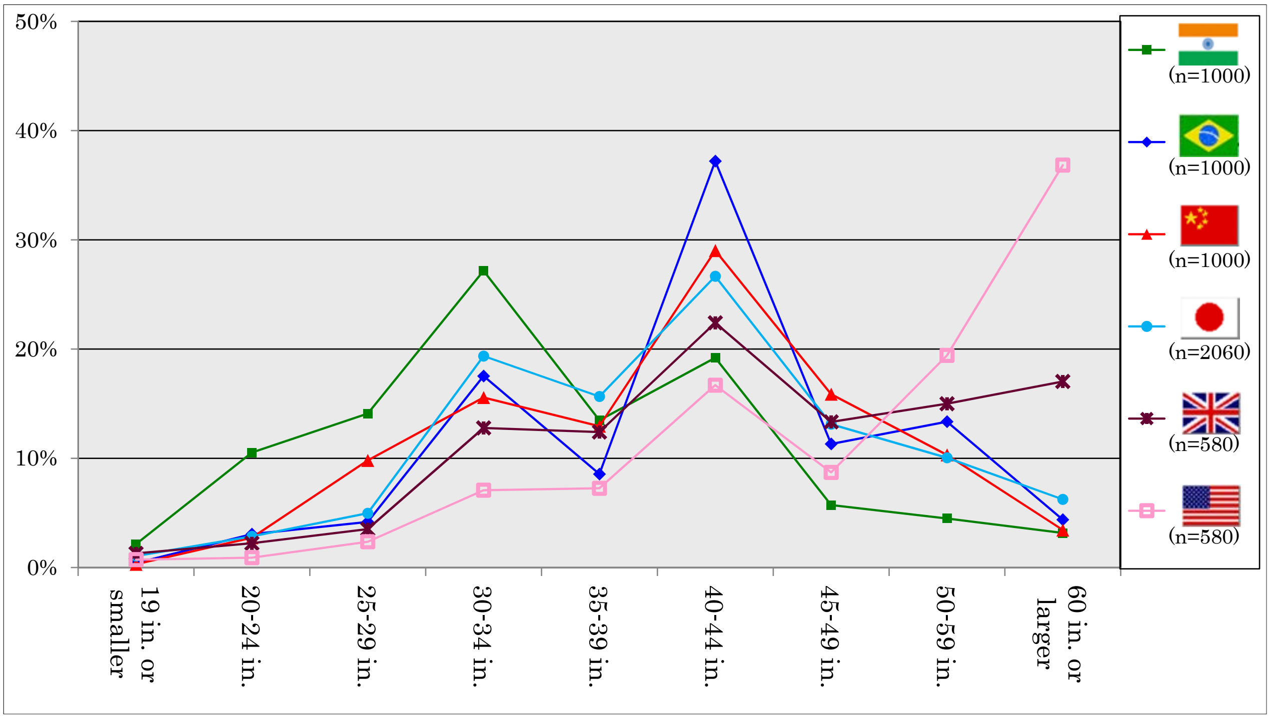


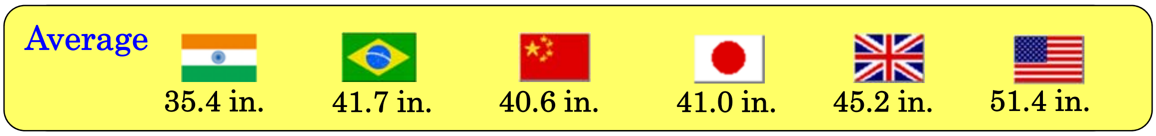
Q7: What size television would you like to put in your living room, etc. in the future to mainly use with your family and such?





Q8: What size television could you actually fit in the room (e.g. living room) where you would put the television to be mainly watched with your family and such?

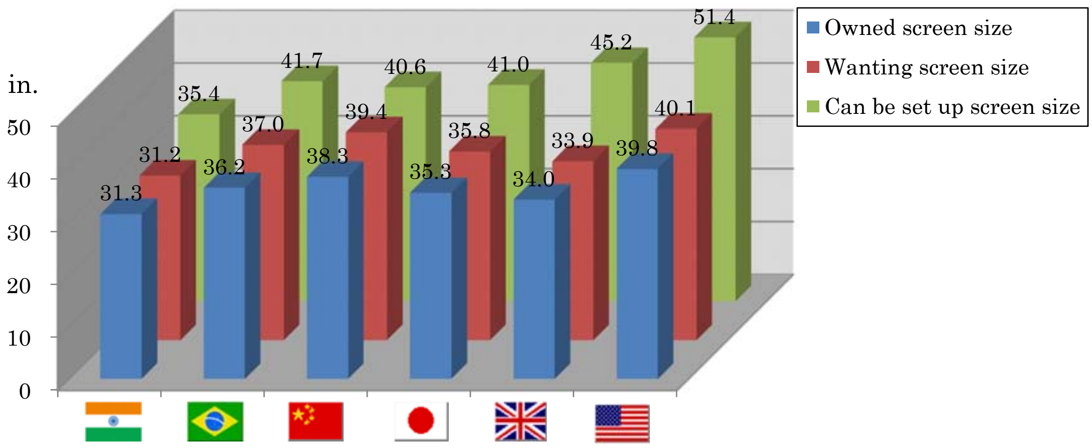




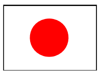
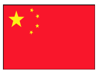
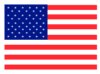
Average

	① Owned screen size	② Wanting screen size	③ Can be set up screen size	② − ①	③ − ①	③ − ②
	31.3	31.2	35.4	-0.1	4.2	4.2
	36.2	37.0	41.7	0.8	5.5	4.7
	38.3	39.4	40.6	1.1	2.2	1.2
	35.3	35.8	41.0	0.5	5.7	5.2
	34.0	33.9	45.2	-0.1	11.2	11.3
	39.8	40.1	51.4	0.3	11.6	11.3

(Unit : in.)

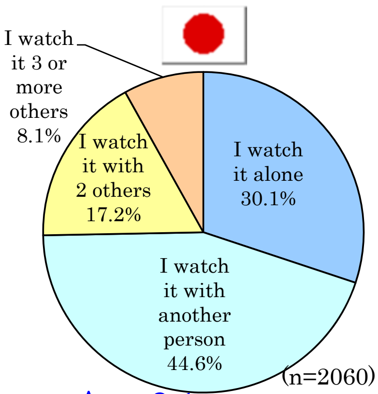


Q9：On average, how many hours a day do you spend watching television?

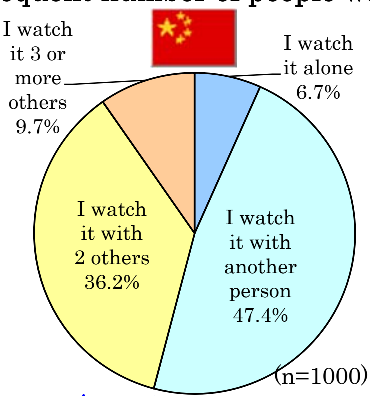
							
Category / Mean		3.6	3.2	3.4	4.1	4.2	4.7
Gender	Male	3.1	3.0	3.1	3.8	4.1	4.8
	Female	4.0	3.4	3.6	4.5	4.3	4.5
Age	20s	3.3	3.0	3.6	3.4	3.8	4.4
	30s	3.3	3.1	3.2	4.0	3.8	4.6
	40s	3.3	3.0	3.2	4.1	4.5	4.3
	50s or more	3.9	3.6	3.4	4.6	4.4	5.0

(Unit : hour)

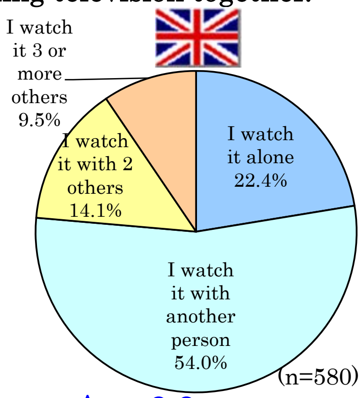
Q10：What is the number of people at your home who watch the television that you mainly watch in the living room with your family and such?
※Please include yourself in the number.
※Answer with the most frequent number of people watching television together.



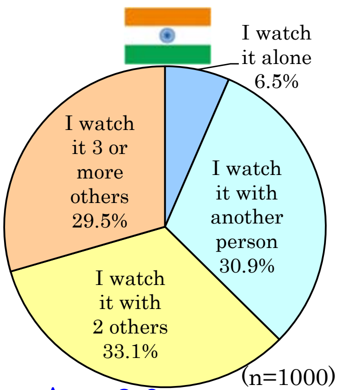
Avg：2.1 persons



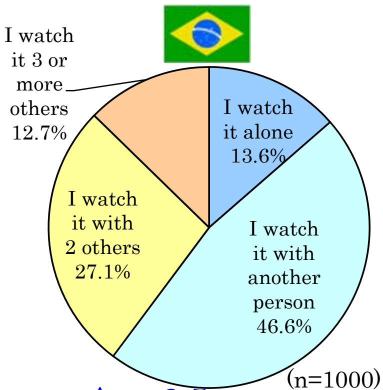
Avg：2.5 persons



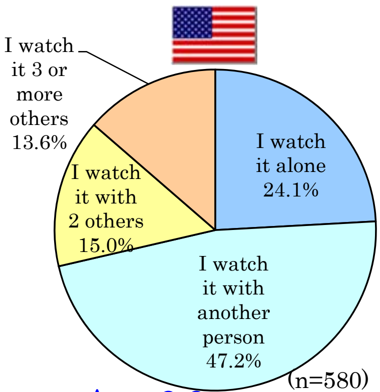
Avg：2.2 persons



Avg：3.0 persons

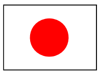
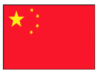
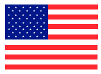


Avg：2.5 persons

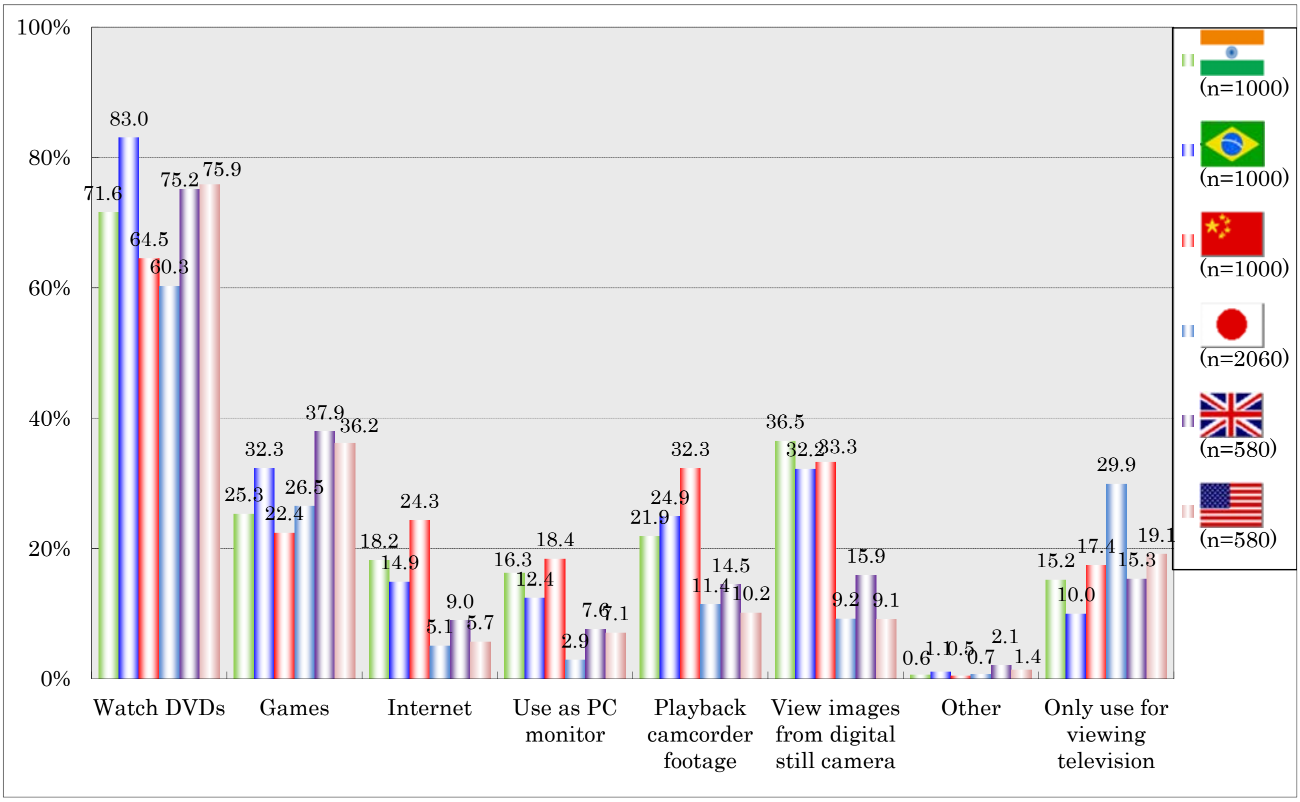


Avg：2.2 persons

Q11: What kinds of programming do you frequently watch on the television that you mainly watch in the living room with your family and such. Choose up to three.

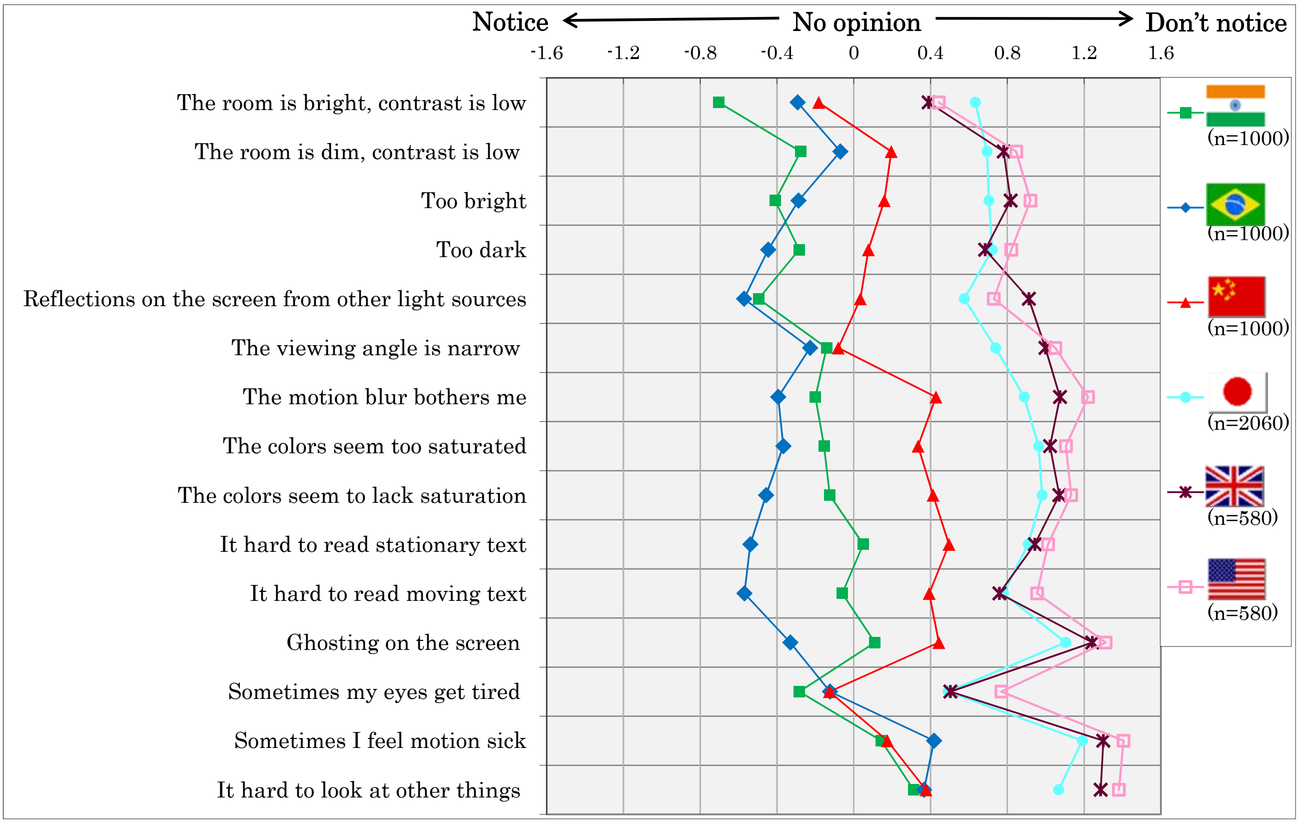
												
Order	**Genre**	**Frequency (%)**	**Genre**	**Frequency (%)**	**Genre**	**Frequency (%)**	**Genre**	**Frequency (%)**	**Genre**	**Frequency (%)**	**Genre**	**Frequency (%)**
1	News	71.0	News	84.7	News	72.1	News	70.5	Movies	56.4	Movies	59.3
2	Variety	45.3	Drama	67.9	Movies	53.2	Movies	47.1	News	53.1	News	56.6
3	Drama	42.3	Movies	33.3	Music	33.5	Drama	45.6	Drama	52.6	Drama	44.8
4	Information and talk show	30.7	Variety	32.9	Sports	32.0	Sports	41.3	Documentary, learning	37.8	Sports	31.2
5	Sports	25.0	Sports	32.5	Drama	24.5	Information and talk show	24.6	Sports	27.4	Documentary, learning	27.2
6	Movies	24.3	Information and talk show	16.4	Information and talk show	19.4	Documentary, learning	19.7	Variety	15.3	Variety	15.0
7	Documentary, learning	18.6	Documentary, learning	12.7	Documentary, learning	11.7	Cartoons/ animation	18.4	Information and talk show	12.1	Cartoons/ animation	14.1
8	Cartoons/ animation	11.8	Cartoons/ animation	6.8	Variety	11.2	Variety	15.6	Music	11.4	Information and talk show	8.8
9	Music	10.1	Music	6.1	Cartoons/ animation	11.1	Music	4.3	Cartoons/ animation	9.8	Music	5.5

Q12: This question concerns the LCD television that you mainly watch in the living room with your family and such. Do you use the television for anything else other than watching television?



Q13: This question concerns the television that you mainly use at home LCD. For each statement below, choose one response that best applies to you.

Weighted average (Definitely notice it: -2 ～ Don't notice it: +2)



Q14: Which of the following features do you think are necessary?

Weighted average (Not required: +1 Will use if available: +2 Must have: +3)