Useful visual field at a homogeneous background for old and young subjects

N. Itoh
K. Sagawa
National Institute of Advanced Industrial Science and Technology (AIST)
1-1-1 Higashi, Tsukuba, Ibaraki, Japan
E: nana-itoh@aist.go.jp

Y. Fukunaga
Tsukuba University of Technology
Tsukuba, Ibaraki, Japan

N.Itoh, K.Sagawa, F.Fukunaga. Useful visual field at a homogeneous background for old and young subjects. Gerontechnology 2009; 8(1):42-51; doi:10.4017/gt.2009.08.01.010.00. The study investigates age-related changes of the entire visual field. The useful visual field was measured with 2 or 4 degrees visual angle target disks of different luminance contrast (experiment 1: n=98) or color (experiment 2: n=95), against a homogeneous background. **Methods** A 'change-blindness' method was adopted to avoid effects of sudden target onset. Screen sizes were 4 m (width) by 2.6 m (height), corresponding to visual angles of 120 deg (horizontal) and 100 deg (vertical). **Results** In all experiments, older subjects showed a smaller size of the useful visual field. **Conclusion** The results have design implications for presenting visual information used by older adults in daily life such as road signs and destination labels of trains.

Keywords: useful visual field, aging, eccentricity, luminance, color

Both indoors and outdoors, public visual information such as road signs and destination labels of trains often appears in our peripheral visual field. It is not always easy to detect or notice. This problem is likely to be more severe for older adults because visual acuity[1], contrast sensitivity[2–4], and size of visual field[5,6] generally decrease with advancing age. Obviously it is desirable to design visual information easily detectable for older people. Three main factors must be considered: (i) visual properties of information: color, contrast, size, and shape; (ii) positioning and layout of the information; (iii) cognitive considerations to make the information directly understandable. Design of factors (i) and (ii) should be based on perception of older adults. The visual field range is an important factor regarding position and layout, especially how to place visual information. If visual information is presented within the visual field and is detectable, even if it is not legible or comprehensible initially, it is possible to conduct eye movements and see it with central vision to read or observe it carefully. However, it is difficult to define the visual field range for older adults because it depends on visual target properties, and, for homogeneous backgrounds, the area of detection in real life is large. For these reasons, reliable data have remained elusive to date.

Prior reports have described many aging effects related to the visual field. Results showed that loss of visual field affected older adults' mobility in various ways such as an increased risk of falling downstairs[7], an increased number of stumbling over bumps, and a decreased walking speed[8]. Regarding visual-field-related performance, a series of studies specifically assessed the useful field of view (UFOV), examining how UFOV changed as a function of age[9–13]. Some studies investigated how reduction of UFOV of older adults was related to driving skills[14,15].

Because of the origin of the UFOV studies, most were focused on divided attention (central or peripheral). Consequently, the results always contained cognitive aspects. Although results represented the age-dependence of UFOV and were informative to understand older adults' behavior, the results did not indicate the maximum range of the visual field as determined by the detection limit.

If the visual field area were applied to the design of visual information, it should reflect two aspects of daily life: (i) Visual information signals should be sufficiently large to meet the actual visual field of observers; (ii) it should reflect the natural viewing condition. To fulfill both aspects to the greatest possible degree, a large screen and the concept of 'change-blindness' method were adopted in this study for target presentation. The change-blindness method was originally conceptualized because it is difficult to perceive local changes if a blank field is projected in a brief period because of the disturbing perception of flicker[16]. Visual suppression is concomitant with blinks and eye movements. So, the 'change-blindness' paradigm reflects the condition of natural behavior[16-18]. When observers viewed a sequence of displays alternating between an image of a scene and the same image changed in some way, they often sensed the change even though they had no visual experience of it[18]. According to these previous studies, the 'change-blindness' paradigm makes it possible to measure the visual field area of detecting a target without disturbing effects of target onset.

Previous reports have described that distractors and visual clutter affect older adults' search efficiency[1–3]. However, no reports in the relevant literature have described effects of target luminance and target color on detection rates.

In the present study, effects of these target factors on detection were investigated by measuring the useful visual field for older and younger adults in two different target conditions. The study is intended to develop a method for evaluating the ability to detect visual information and signs for older adults, and to derive the relevant design principles. The target variables (luminance, color) were examined separately to elucidate effects of the basic target properties. .

Methodology

Experimental setup

The application ran on a personal computer (Power Mac G4; Apple Computer Inc.) connected to a double monitor (L360 Flex Scan, Eizo Nanao Corp.) for control conditions, with a rear projection screen (Stewart Film screen) to project the targets. A large white uniform screen was illuminated from behind. A projector (ELP9100; Seiko Epson Corp.) was used. The projected target images consisted of a background field and a circular target disk of varying luminance, color, and size. Subjects were requested to detect a single test target presented along eight different axes from fixation and at different eccentricities (10–60 deg at 10 deg spacing)

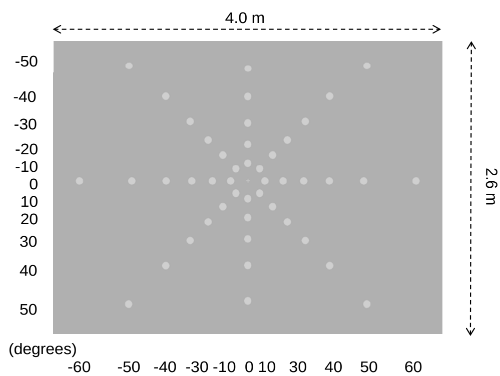

Figure 1. Screen size is 4 m wide × 2.6 m high, corresponding to visual angles of over 120 deg and 100 deg; target size is 2 or 4 deg; In a dark room, all participating subjects wore corrective lenses to secure maximum visual acuity; They looked at the screen using their right eye only at a distance of 1 m. Target positions are at a separation of 10 degrees visual angle at 8 different directions from fixation

(*Figure 1*). The target was presented randomly multiple times at each of 46 locations. The order and duration of the target projections were 1000ms for background, 250ms for the blank field, and 200ms for the target and background (*Figure 2*). The projection started when the subject had pressed one large start-button of a keypad while fixating the center of the projection (+ sign). In previous studies of change-blindness, brief blank fields were placed between alternating displays of an original and a changed scene; the method is called 'flicker technique'. The present study was not designed to examine the effect of the change of image, but to measure an area of detection within one glance. The blank field and the target projections were not repeated, thereby minimizing the involvement of eye movements and memory.

Looking at the screen, the subjects responded to each appearance of the target using the keypad. The keypad had eight buttons positioned radially, corresponding to the axis on which the target appeared. For each trial, the subjects were instructed to indicate the direction of the target using the keypads when the target was projected. Subjects were requested to press a button for one of eight directions for all trials, even in cases where it was difficult to see clearly. According to a prior study, when observers answered the correct radial direction, they also knew the correct eccentricity, although when observers did not answer the correct radial direction, the correct eccentricity value was reported much less frequently[11]. Therefore, in this study, we asked the subjects to respond with radial directions only.

The target position order was randomized for each subject. Each subject performed 129 trials for training. In experiments 1 and 2, the subject answered 3-5 times for each position of the target. In experiment 1, the number of trials at each position was 170 for older subjects and 155 for younger subjects. The unequal number of trials of each group occurred because of the different numbers of

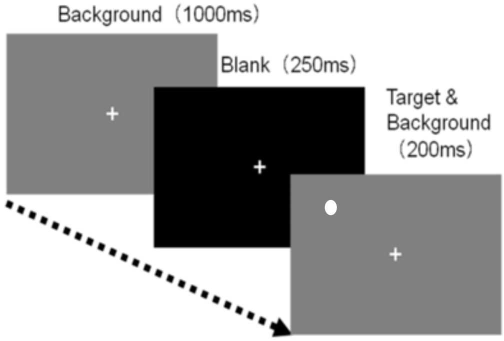

Figure 2. Projection sequence of background, blank field, and target + background screens; Projection durations are shown in parentheses; The blank field serves to mask the sudden appearance of the target
Experiment1: Luminance of background: 20 cd/m^2, target 1 (low contrast): 24 cd/m^2, target 2 (medium contrast): 28 cd/m^2, target 3 (high contrast): 36 cd/m^2
Experiment2: Luminance of background and target: 10 cd/m^2

stimuli for the various subjects. Each subject attended between three and five sessions. Averages were 3.27 sessions of older subjects and 3.36 sessions of younger subjects. In experiment 2, the numbers of trials per position were 144 for older participants and 142 for younger subjects. Because of the same reason, unequal numbers of trials of each group occurred. Averages of sessions were 3.00 for older subjects and 3.02 for younger subjects.

Stimuli

Effect of target luminance / contrast

In experiment 1, targets were solid white disks of 2 degrees visual angle, luminances $L_{t=}$ 24, 28, or 36 cd/m^2 and the background L_b = 20 cd/m^2 white (gray). Luminance contrasts were (Lt-Lb)/Lb = 20, 40 and 80% respectively.

Effect of target color

In experiment 2 the targets were solid red, green, and blue disks (4 degrees visual angle) with luminance of 10 cd/m^2; the background was 10 cd/m^2 white (gray), so there was no luminance contrast. All luminances were in photopic units. Three chromatically different types of color (low-saturated: R1, G1, B1; median-saturated: R2, G2, B2; high-saturated: R3, G3, B3), were adopted for

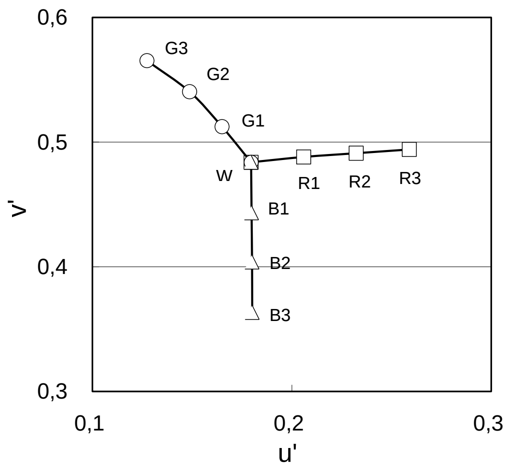

Figure 3. Target colors used in experiments 1 and 2 are shown on 1978 CIE LUV Color Space[19]; chromatic differences in color of each type were set to the same level to examine color effects

each hue as shown in the CIE LUV Color space diagram (*Figure 3*)[19].

Subjects

Participants were 52 older (62–81 yrs; average 70 yrs) and 46 younger (20–27 yrs; average 23 yrs) subjects for experiment 1, and 48 older (62–81 yrs; average 70 yrs) and 47 younger (20–27 yrs; average 22 yrs) subjects for experiment 2. None had any record of eye disease either before or during the study that might have caused visual function loss and no subject reported any ocular pathology (e.g., macular degeneration, glaucoma, cataract). Before the experiment, each subject's visual acuity was adjusted to the maximum attainable level using corrective lenses. Before the experiment, authors obtained informed consent from the subjects. Subjects were rewarded for their participation.

Results and discussion

Detection rate of useful visual field

Effect of luminance contrast

For statistical analyses, percentages of correct data were transformed using the arcsine of the square root of percent correct data following the method described in previous studies[11,13,14].

Figure 4 A-C shows the transformed percentage of correct answers versus luminance contrast. Analysis of variance (ANOVA) was performed for age (two positions) × luminance contrast (three positions) × eccentricity (six positions). No three-way interaction existed between age, eccentricity, and luminous contrast ($F[10, 222]=0.496$, $P>0.05$), although significant interactions existed between age and eccentricity ($F[5, 222]=4.337$, $P<0.05$) and between luminous contrast and eccentricity ($F[10, 222]=1.991$, $P<0.05$). However, no significant interaction was found between age and luminous contrast ($F[2, 222]=0.359$, $P>0.05$). Therefore, to examine age effects, main effects of age were investigated under each condition of luminous contrast.

For low (20%) luminous contrast, marked age dependence was observed at all eccentricities; for higher contrasts the age difference was significant only from the mid-periphery onwards; from 30 deg in 40% contrast and from 40 deg in 80%. Therefore, when target-to-background contrast was low, older subjects showed more difficulty in seeing the target than younger subjects did. However, if contrast was higher and target position was close to the center, age dependence lessened. In addition, when the contrast of target and background was low (20%), eccentricity dependence appeared at 40 deg for older subjects and 50 deg for younger subjects. If the contrast increased, the eccentricity dependence appeared in a more eccentric position, especially in younger adults. These results demonstrated that age differences are greater when the contrast between the target and background is lower and the target position set in further eccentricities.

Effect of color (hue and saturation)

Figures 4 D-L portray transformed percentages corrected according to the respective colors red, green and blue.

Analysis of variance (ANOVA) was performed for age (two positions) × color (three positions) × eccentricity (six positions). No three-way interaction was found between

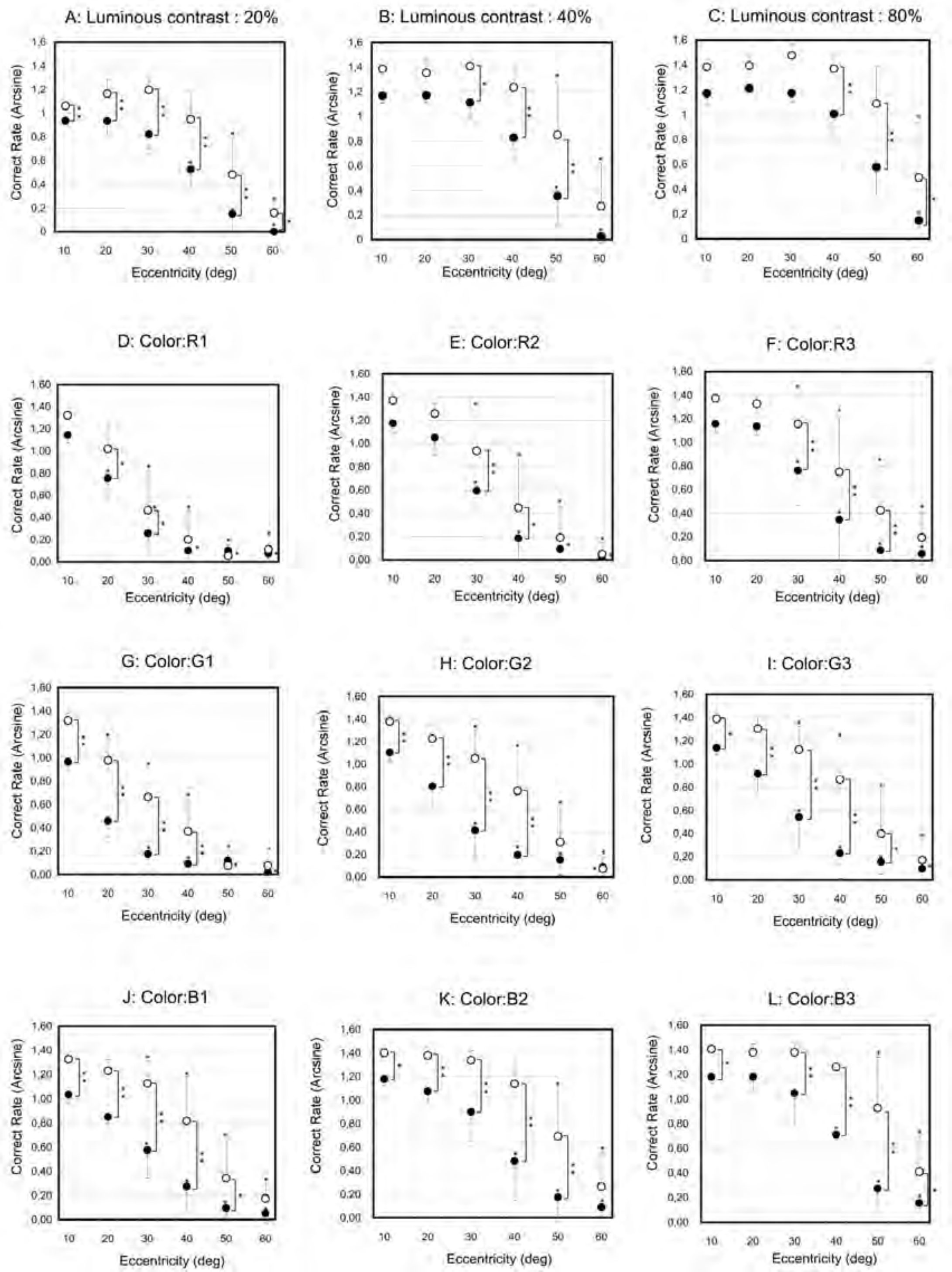

*Figure 4. Arcsine-transformed % of correct answers; (A)-(C) different luminance contrasts; (D)-(F) red color; (G)-(I) green color, (J)-(L) blue color; • = older subjects; ○= younger subjects; difference between older and younger subjects, or from the rate of eccentricity of 10 deg: *= p<0.05, **=p<0.01*

age, eccentricity, and respective colors (R: $F[10, 240]=0.600$, $P>0.05$, G: $F[10, 240]=1.273$, $P>0.05$, B: $F[10, 240]=1.282$, $P>0.05$). However, a significant interaction was found between age and eccentricity, except for red (R: $F[10, 240]=1.630$, $P>0.05$, G: $F[10, 240]=12.891$, $P<0.01$, B: $F[10, 240]=5.824$, $P<0.05$), and between color and eccentricity, except for green (R: $F[10, 240]=4.130$, $P<0.05$, G: $F[10, 240]=1.636$, $P>0.05$, B: $F[10, 240]=5.824$, $P<0.05$). Then, effects of age on each condition of color were investigated.

For the red target, the nearest periphery (10 deg) and the most distant periphery (60 deg) are not so much different between older and younger subjects. Age differences were found to be significant at median eccentricity (30–50 deg) when the color saturation of the target was high (R3). When the target color saturation was low (R1, R2), the age difference was significant at middle eccentricity (R1, 20 and 30 deg; R2, 30 and 40 deg). No age difference was found at greater eccentricity (*Figure 4 D-F*).

For the green target, unlike red, from the nearest periphery (10 deg) to 40 deg, the age differences were found to be significant. Furthermore, age difference existed at 50 deg only in G3. No age difference was found for 60 deg in any of the three saturations (*Figure 4 G-I*).

For a blue target, from the nearest periphery (10 deg) to 50 deg, the age difference is significant in all three saturations (*Figure 4 J-L*).

These results underscore the differences of colors. Only for the red target did age difference not appear in the near periphery at both lower and higher saturation colors, except R3, for which an age difference appeared at 50 deg. In general, the percentages of correct answers were larger at higher saturation than at lower saturation for both age groups. For green and blue targets, effects of saturation in the near periphery were larger in younger subjects than in older subjects; this did not happen for the red target.

According to Sagawa and Takahashi[20], gradual reduction of luminous efficiency with age is observed, using foveal presentation, flicker photometry, and direct brightness matching in the short-wave region. It can be considered that reduction of luminous efficacy also occurs in the near periphery of the visual field. Therefore, age differences of detection are to be expected for green and blue targets. In addition, light sensitivity of older adults became low in the far periphery[5]; and rod sensitivity in the short wave region is better for younger people[21]. Probably for that reason, an age difference appeared when the blue target appeared in the far periphery (50 and 60 deg), which is perceived mainly by rods.

Ball et al.[9] and Seiple et al.[11] measured only in divided attention in the mid-periphery area within 30 deg. In those cases, it was difficult to infer age differences probably because of the cognitive aspect: attentional load, with both cognitive and sensory or sensory aspects only. For Sekuler et al.[12], both focused and divided attention were measured. The results reflected a focused attention condition (i.e. no attentional load), showing increasing error rates from the youngest age group (15-24) observed at each age group (from 30's to 80's) and the gap became wider with increased age when no attentional load was used. Regarding the effect of eccentricity in focused attention, they found that performance declined gradually with increasing eccentricity, which was not detected in a prior study using divided attention[9,11].

As described in these reports, eccentricity dependence appears only at the focused attentional condition. From our experiment, results showed that where decline starts depends on target contrast and color. It became clear that eccentricity dependence existed for almost all target properties.

When the target contrast was low (20%), a decline appeared in the mid-periphery at 40 deg for older adults and 50 deg for younger adults, but if the contrast of the target was high (80%), decline appeared at 50 deg both in older and younger adults. In case of the colors, generally, the decline started at the near-periphery (20 or 30 deg) with low saturation colors for both older and younger subjects. As saturation increased, it started in more distant regions. Furthermore, comparison with the younger subjects showed that the decline of older subjects was steeper, especially for the near and mid-periphery. Regarding decline in the near periphery (20 deg), green is steepest, followed by red and blue in that order.

Size of the useful visual field

For practical usage of the data, the actual size of the useful visual field with accuracy of 50% is shown and differences between older and younger subjects were analyzed.

Figure 5 portrays relative sizes of the visual field for targets of different luminance (experiment 1) and color: red, green, and blue (experiment 2). The left sides of both figures show data for younger subjects; the right sides for older subjects.

Age effects were observed for both luminance contrast and color. Figure 5 A-B portrays the difference between older and younger subjects: it increased as the target luminance contrast decreased.

As compared to red and green targets, blue targets were detected at greater eccentricities along all axes, for both young and older subjects (Figure 5 C-H). These results resemble those of a previous study in which color images in the peripheral visual field were observed[22], where an area of highly saturated blue (50% unique blue component) is close to the area of B3 of younger subjects in this experiment. An area of highly saturated green (50% unique green component) is close to the area of G3 of younger subjects in this experiment. The difference in useful visual fields between red and green targets in older subjects is greater than the difference observed in younger subjects.

Visual function of subjects

All subjects in our study used corrective lenses. Some prior studies selected subjects according to their visual acuity[9,11]. Results showed that their results were obtained not only by people with good visual acuity and good accommodation ability. Owsley et al.[10] reported that, despite having good visual field sensitivity, many older adults have great difficulty locating objects of interest in an environment. In their experiment, the task required divided attention, which might have caused some effects of age difference because cognitive abilities depend on age. In our study, results showed that although no divided attention load was imparted, older subjects had difficulty locating objects. As described before, no effect of the decreased visual acuity was found in our results. Therefore, in our experiments the age difference of the useful visual field simply reflects the visual function of detectability in peripheral areas for each age group.

Synergy of luminance contrast and color

Results showed in both cases that detectability of luminance contrast difference only (without color difference) and of color difference only (without luminance difference) had age effects. Consequently, it seems that the isoluminance target was difficult to detect in the peripheral area for older subjects because the areas of R3, G3, and B3 which use large size of target (4 degree visual angle) are smaller than areas of luminance contrast 20% (2 degree visual angle), while in the case of the younger subjects, the B3 area was almost identical to the area of luminance contrast 80% (*Figure 5*). According to a prior study, visual search is slower with isoluminant color stimuli than with luminance stimuli[23]. In our study, the visual search time was not measured, but it appeared more difficult to detect an isoluminance target than a luminance contrast target, especially for older adults. For that reason, the actual size

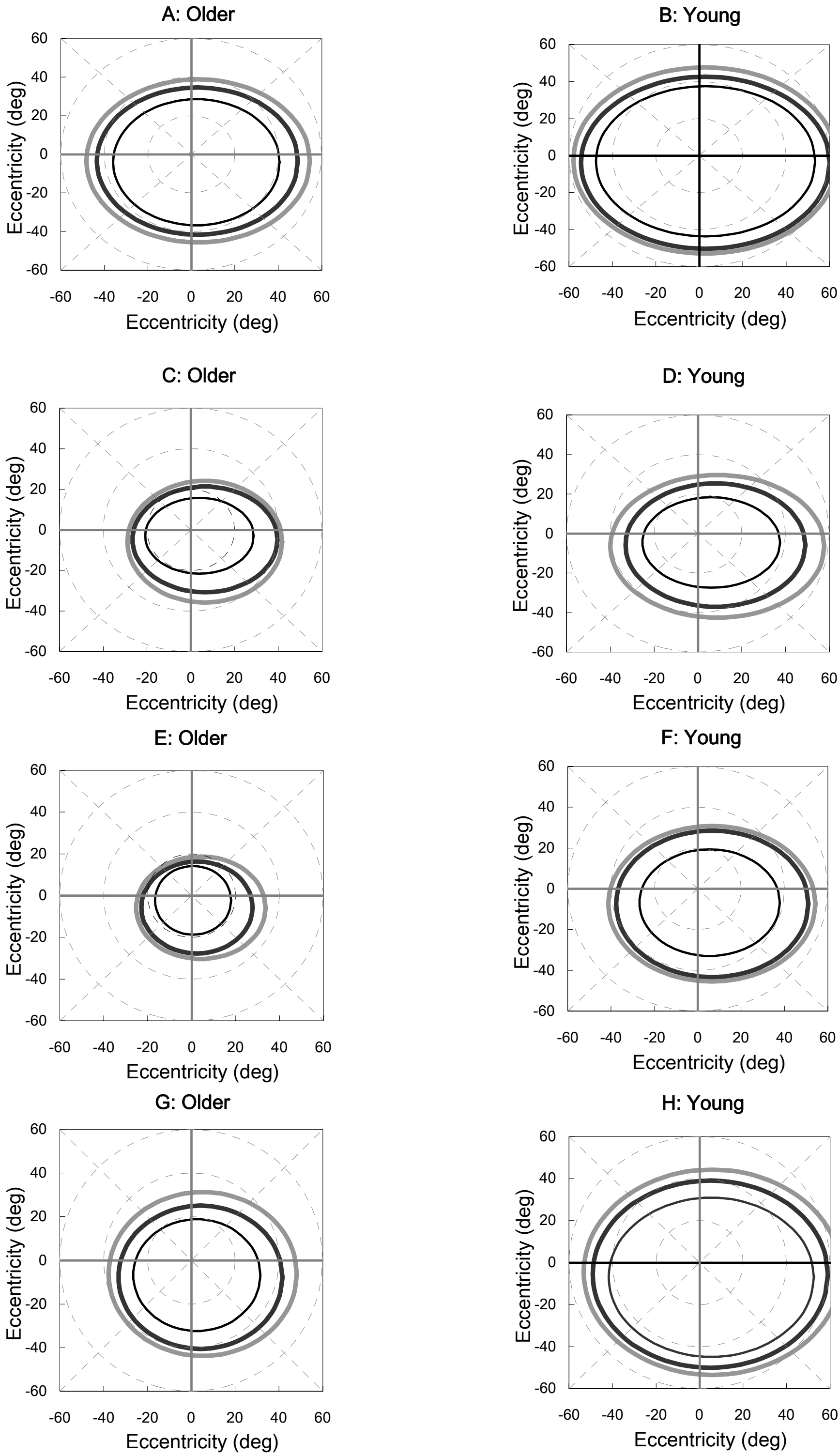

Figure 5. Useful visual field dependence on luminance or color; (A)-(B) luminance ((Lt-Lb)/Lb) 20%=narrow black line; 40%=thick black line; 80%=thick gray line; (C)-(D) Red color: R1=narrow black line; R2=thick black line; R3=thick gray line; (E)-(F) green color: G1=narrow black line; G2=thick black line; G3=thick gray line; (G)-(H) blue color: B1=narrow black line; B2=thick black line; B3=thick gray line

of useful visual field shows only when the criterion for target detection was 50%. Synergic effects of luminance and color have not been investigated yet; further investigation is necessary to elucidate these.

Conclusion

The main goals of this study were to clarify the useful visual field of older and younger adults using the change-blindness paradigm for consideration of natural viewing conditions. We also sought to elucidate the age dependence of the effects of target properties: luminance contrast and color difference. We also showed the actual size of the useful visual field as a guide for designing the visual information layout.

Two experiments demonstrated that age differences were greater when the luminance contrast between the target and the background was smaller and the target position was set at further eccentricities. For the color difference of the target, compared to younger subjects, the decline with eccentricity of the correct percentage of older subjects was steeper, especially in the near and mid-periphery. In addition, the blue target was better detected in far eccentricity than either red or green for both younger and older subjects. Nevertheless, age dependence of detectability for the blue target appeared at all eccentricity positions. In the near periphery, the low-saturation green target (G1) showed the worst detectability, especially for older subjects. For designing visual information, choice of color and luminance contrast is important to minimize age effects of detectability.

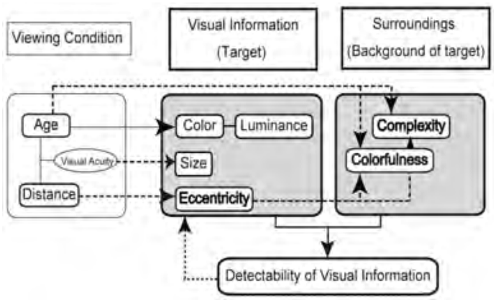

Figure 6. Schematic model for the design of Visual Information; if viewer age, viewing distance, and eccentricities are known, ideal target variables including color, size, and position, and layout of the surrounding visual information can be estimated based on quantitative experimental data

Utilization of results

From this study, age-related differences in detectability were found to depend on the target's luminance contrast and color (hue and saturation). A prior study revealed that detectability depends on the complexity and color of the background[24]. To maximize detectability and visibility of visual information, especially for older adults, it is necessary to consider all these factors.

Figure 6 depicts future steps that would enable designers to estimate ideal target variables based on characteristics of an intentional viewer and environmental viewing conditions.

References

1. Pitts DG. Visual acuity as a function of age. Journal of the American Optometric Association 1982;53(2):117-124
2. Owsley C, Sekuler R, Siemsen D. Contrast sensitivity throughout adulthood. Vision Research 1983;23(7):689-699; doi:10.1016/0042-6989(83)90210-9c
3. Pardhan S. Contrast sensitivity loss with aging: Sampling efficiency and equivalent noise at different spatial frequencies. Journal of the Optical Society of America A–Optics Image Science and Vision 2004; 21(2):169-175; doi:10.1364/JOSAA.21.000169
4. Rohaly AM, Owsley C. Modeling the contrast-sensitivity functions of older adults. Journal of the Optical Society of America A–Optics Image Science and Vision 1993;10(7):1591-1599; doi:10.1364/JOSAA.10.001591
5. Haas A, Flammer J, Schneider U. Influence of age on the visual fields of normal subjects. American Journal of Ophthalmology 1986;101(2):199-203
6. Jaffe GJ, Alvarado JA, Juster RP. Age-related-changes of the normal visual field. Archives of Ophthalmology 1986;104(7):1021-1025
7. Freeman EE, Munoz B, Rubin G, West SK. Visual field loss increases the risk of falls

in older adults: The Salisbury eye evaluation. Investigative Ophthalmology and Visual Science 2007;48(10):4445-4450; doi:10.1167/iovs.07-0326

8. Turano KA, Broman AT, Bandeen-Roche K, Munoz B, Rubin GS, West SK, Team SEEP. Association of visual field loss and mobility performance in older adults: Salisbury eye evaluation study. Optometry and Vision Science 2004;81(5):298-307; doi: 10.1097/01.opx.0000134903.13651.8e
9. Ball KK, Beard BL, Roenker DL, Miller RL, Griggs DS. Age and visual-search : Expanding the useful field of view. Journal of the Optical Society of America A – Optics Image Science and Vision 1988;5(12):2210-2219; doi:10.1364/JOSAA.5.002210
10. Owsley C, Ball K, Keeton DM. Relationship between visual sensitivity and target localization in older adults. Vision Research 1995;35(4):579-587; doi: 10.1016/0042-6989(94)00166-J
11. Seiple W, Szlyk JP, Yang S, Holopigian K. Age-related functional field losses are not eccentricity dependent. Vision Research 1996;36(12):1859-1866; doi:10.1016/0042-6989(95)00288-X
12. Sekuler AB, Bennett PJ, Mamelak M. Effects of aging on the useful field of view. Experimental Aging Research 2000;26(2):103-120; doi: 10.1080/036107300243588
13. Edwards JD, Ross LA, Wadley VG, Clay OJ, Crowe M, Roenker DL, Ball KK. The useful field of view test: Normative data for older adults. Archives of Clinical Neuropsychology 2006;21(4):275-286; doi: 10.1016/j.acn.2006.03.001
14. Roge J, Pebayle T, Lambilliotte E, Spitzenstetter F, Giselbrecht D, Muzet A. Influence of age, speed and duration of monotonous driving task in traffic on the driver's useful visual field. Vision Research 2004;44(23):2737-274; doi:10.1016/j.visres.2004.05.026
15. Roge J, Pebayle T, Campagne A, Muzet A. Useful visual field reduction as a function of age and risk of accident in simulated car driving. Investigative Ophthalmology and Visual Science 2005;46(5):1774-1779; doi:10.1167/iovs.04-0540
16. Rensink RA, O'Regan JK, Clark JJ. To see or not to see: The need for attention to perceive changes in scenes. Investigative Ophthalmology and Visual Science 1996;37(3):978-978; doi:10.1111/j.1467-9280.1997.tb00427
17. O'Regan JK, Rensink RA, Clark JJ. Change-blindness as a result of 'mudsplashes'. Nature 1999;398(6722):34-34; doi:10.1016/0042-6989(94)00166-J
18. Rensink RA. Visual sensing without seeing. Psychological Science 2004;15(1):27-32; do i:10.1111/j.0963-7214.2004.01501005
19. International Commission on Illumination (CIE). Colorimetry 3rd edition. Technical Report 15:2004. Vienna: Bureau Central CIE; 2004
20. Sagawa K, Takahashi Y. Spectral luminous efficiency as a function of age. Journal of the Optical Society of America A–Optics Image Science and Vision 2001;18(11):2659-2667; doi:10.1364/JOSAA.18.002659
21. Sagawa K, Takeichi K. Spectral luminous efficiency functions in the mesopic range. Journal of the Optical Society of America A–Optics Image Science and Vision 1986;3(1):71-75; doi:10.1364/JOSAA.3.000071
22. Sakurai M, Ayama M, Kumagai T. Color appearance in the entire visual field: Color zone map based on the unique hue component. Journal of the Optical Society of America A–Optics Image Science and Vision 2003;20(11):1997-2009; doi:10.1364/JOSAA.20.001997
23. Skottun BC, Skoyles JR. Visual search: Magno- and parvocellular systems or color and luminance processes? International Journal of Neuroscience 2008;118(9):1259-1267; doi:10.1080/00207450701239434
24. Itoh N, Fukunaga Y, Sagawa K. Useful field of view (2) Method for designing and evaluating the detectability of visual information for the elderly. In Proceedings of the CIE Midterm Meeting and International Lighting Congress; 2005; CD-ROM