Influence of aging on the color visual field in humans
A cross-sectional study

Takeshi Yada, OTR, MS,a,b Osamu Tokumaru, MD, PhDb,c,†, Nobuoki Eshima, DSc,d,e, Takaaki Kitano, MD, PhD,f Isao Yokoi, MD, PhDg

Abstract
Age-related narrowing of the visual field is observed in the elderly, which leads to reduced cognitive and psychomotor functions. The aim of the present cross-sectional study was to determine the influence of aging on the visual field for color vision in humans, with respect to angular thresholds for object detection and color detection.

The subjects were divided into the elderly group (mean 76.1-year-old [70–89]) and the control group (25.2 [18–47]). Visual fields for different colors (blue, green, yellow, and red) were measured by manual kinetic perimetry and evaluated in terms of 2 measures of visual-field width: angular thresholds for object detection and those for color detection.

While angular thresholds for object detection were significantly wider than those for color detection in the control group ($P < .001$), there was no difference in the elderly group ($P = .06$). Moreover, angular thresholds for object detection were significantly wider in the control group than in the elderly group ($P = .019$), but angular thresholds for color detection were not significantly different between the 2 groups ($P = .903$).

The observed age-related changes in angular thresholds for object detection in color vision may reflect an age-related reduction in rod function. Stable cone function might explain the preserved angular thresholds for color detection in the elderly.

Abbreviations: TC = threshold for color-detection, TO = threshold for object-detection.
Keywords: aging, color vision, detection, visual field

1. Introduction
A decline in sensory function is commonly experienced with aging.[1] The normal aging process degrades several visual functions including visual fields. After adolescence, chromatic threshold increases as age increases,[2] and contrast sensitivity declines more rapidly in the periphery with age.[3] In particular, age-related reduction in visual fields leads to reduced cognitive[4] and psychomotor functions.[5] Diminished vision is also associated with fear of falling,[6,7] depression,[7,8] increased mortality, physician visits, hospitalization, and thus family stress.[9] In addition, diminished vision is associated with limitations in the performance of activities of daily living[9] and the activities of social life in the elderly. For example, impaired vision due to aging may be linked to loneliness and reduced quality of life.[8,10] Reduction in visual fields would cast a critical influence not only on activities of daily living but also on the safety of the elderly. Since our society uses a variety of safety signs with color, the decline in color visual fields could also impact the safety of the elderly.

However, the authors find few studies to date on age-related changes in the visual fields for different colors. For example, Farah et al examined visual field in the elderly using Humphrey field analyzer, thus the evaluation was conducted only within central 30° without information regarding color presented.[10] Although other studies in 80 and 90 also reported age-related decreases in the visual field[11–15] age-related changes in visual fields were not focused with respect to color.

The objective of the present study was to fill this gap; to reveal age-related changes in visual fields with respect to color. We hypothesized that age-related reductions in visual fields would be observed regardless of the color of the stimuli. Thus, we conducted a cross-sectional study to demonstrate age-related changes in visual fields for color vision.
2. Materials and methods

2.1. Ethical considerations

The study conformed to the standards set by the World Medical Association Declaration of Helsinki Ethical Principles for Medical Research involving Human Subjects as amended in 2013 and was conducted with the approval of the Ethics Committee of the Oita University Faculty of Medicine (approval number 689) consistent with the World Health Organization “Standards and operational guidance for ethics review of health-related research with human participants” (2011). Each participant provided written informed consent prior to the study start.

2.2. Participants

A total of 39 participants were enrolled in the present cross-sectional study as unpaid volunteers. All participants underwent a visual field examination of the right eye. Those aged 70 years or older were classified as the elderly group (n=13, male/female = 3/10, mean 76.1 [min 70–max 89] years-old), and those aged under 50 years served as the control group (n=26, male/female = 17/9, mean 25.2 [min 18–max 47] year-old). The male-to-female ratio of the elderly group was 3/10 whereas that of the control group was 17/9. Thus the sex ratios of the 2 groups were significantly different (P = .019, Fisher exact test). All participants had the normal visual function in ordinary daily life. The participants self-reported no obvious visual field defects nor color vision deficiencies, cataract, glaucoma, pseudophakias (presence of an artificial lens), or other eye diseases. Dementia was ruled out with the Revised Hasegawa Dementia Scale [16] which is significantly correlated with the Mini-Mental Status Examination [17]. No history of drug abuse, neuropsychiatric disorder, or diabetes mellitus was reported.

2.3. Measurement of kinetic perimetry

The Goldmann perimeter and the Humphrey field analyzer are common devices in clinical use for the evaluation of the visual field. However, the Goldmann perimeter is not suitable for a study of color vision. The Humphrey field analyzer is only capable of measuring visual fields for the central 30° of the visual field. Kinetic perimetry is more sensitive for detecting peripheral visual field deficits than conventional static perimetry. [18] Thus, the present study used a manual kinetic perimeter (T.K.K. 101, Takei Scientific Instruments Co. Ltd., Niigata, Japan) with an 8-mm-diameter house-made visual stimulus of visual angle 1.64° (slightly smaller than a Goldmann size V) for evaluation of visual fields for the following 4 colors: blue, green, yellow, and red. The CIE 1931 xy chromaticity coordinates were as follows: blue (0.206, 0.252); green (0.244, 0.521); yellow (0.445, 0.479); and red (0.666, 0.167). All experiments were conducted under photopic conditions (200–350 lux) at the surface of the perimeter (testing distance 285 mm) in accordance with the instruction manual of the instrument, which recommends ≥ 100–300 lux or more.

The participants were adapted to the room light condition (280 lux on average) for approximately 30 minutes while explanations and a practice session were given in preparation for the experiments. The average duration of a practice session was about 10 minutes. Natural pupils without any dilation were used throughout the experiment in order to evaluate visual fields in ordinary daily life. Retinal illuminance was not measured. The first author conducted all measurements by manually moving a visual stimulus from the periphery to the center at a rate of 5° to 10°/s along a selected meridian on the inner surface of the perimeter in accordance with a recommendation by Johnson & Keltner. [19] Each participant had a practice session before data acquisition. Measurements were conducted along 12 meridians spaced at 30°-intervals. The colors and meridians were selected for experimentation in a pseudorandom order. Participants responded orally.

Visual fields were evaluated using 2 kinds of parameters: angular threshold for object-detection (TO) and that for the threshold for color-detection (TC), for each of the 4 colors. TO was the angle at which a stimulus was detected; a 2-interval forced choice procedure (presence or absence). TC was the angle at which the color of the stimulus was correctly identified; a 4-interval forced choice procedure (blue, green, yellow, or red). The data were collected by the first author who was unblinded to the group.

2.4. Statistics

Statistical analyses were performed by R 3.5.0 data analysis software. [20] The data were analyzed by analysis of variance of age group, color of stimulus, and meridian followed as independent factors and TO and TC as dependent factors. Differences between TO and TC were tested by a repeated-measures (within-participant), 2-way analysis of variance design for each age group separately. The effect of group on TO and TC were analyzed with unreplicated measures, 2-way analysis of variance design. The statistical power was estimated to be 83% given the sample sizes above and the difference in means of 5° with a standard deviation of 5°. Values are expressed as means±95% confidence intervals. The significance level was set at .05. Statistical analyses in the present study were supervised by one of the authors with expertise in statistics (NE).

3. Results

3.1. Comparison between TO and TC

In the control group, TO was significantly wider than TC (F1,23 = 50.7, P < .001, Figs. 1A–D). For example, TO/TC along the temporal meridian was 56.2°±7.0°/51.8°±8.3°, 53.6°±7.2°/43.2°±8.5°, 56.9°±6.8°/47.5°±7.0°, and 55.8°±6.4°/46.2°±8.1° for blue, green, yellow, and red, respectively (see Table S1, Supplemental Digital Content, http://links.lww.com/MD2/A761). In contrast, in the elderly group, there were no differences between TO and TC, F1,12 = 4.03, P = .06 (Figs. 1E–H).

3.2. Comparison of TO between the elderly and control groups

Unrepeated measures 2-way analysis of variance revealed significant effects of age on TO, F1,37 = 5.95, P = .019. For each color, TO in the control group was wider than that in the elderly group (Figs. 2A–D). For example, TO along the temporal meridian in the control/elderly groups were 56.2°±7.0°/41.5°±10.2°, 53.6°±7.2°/45.4°±9.3°, 56.9°±6.8°/49.5°±11.3°, and 55.8°±6.4°/49.7°±9.5° for blue, green, yellow, and red, respectively (Table S1, Supplemental Digital Content, http://links.lww.com/MD2/A761).

3.3. Comparison of TC between the elderly and control groups

Unrepeated measures 2-way analysis of variance revealed no significant effects of age on TC (F1,37 = .015, P = 0.903, Figs. 2E–H). For example, TC along the temporal meridian in the control/...
elderly groups was 51.8° ± 8.3°/45.2° ± 10.1°, 43.2° ± 8.5°/43.8° ± 9.4°, 47.5° ± 7.0°/46.2° ± 11.4°, and 46.2° ± 8.1°/47.3° ± 9.5° for blue, green, yellow, and red, respectively (Table S1, Supplemental Digital Content, http://links.lww.com/MD2/A761).

4. Discussion and conclusions
The authors studied the influence of aging on the visual field for different colors using manual kinetic perimetry. The present study revealed 2 features:

1. TO was significantly wider than TC for any color examined in the control group (Figs. 1A–D), whereas we found no differences between TO and TC for any color in the elderly group (Figs. 1E–H), and
2. age had a significant effect on TO (Figs. 2A–D), but not on TC (Figs. 2E–H) for any color examined.

It should be of importance to clarify that only TO was age-dependent and TC was well preserved in the elderly.
The elderly people have preserved the color-discriminating function in the central field of vision while they have lost the function to detect objects in their peripheral field.

In the control group, TO was significantly wider than TC for each color. The authors speculate that TO is related to rods (not cones) function because subjects detected the presence of a target but did not recognize the color at this angle. The authors also speculate that TC is related to the function of cones because the recognition of the color was observed at this angle. Thus between TO and TC, subjects could recognize the presence of the target by the function of rods but could not discriminate its color by the function of cones.

The present study showed significant differences in TO between the age groups for all 4 colors examined (Figs. 2A–D). This finding might reflect an influence of aging on the peripheral rod-cell density. Rod density is decreased by 30% in mid-life. Therefore, reductions in rods due to aging may have led to the reduction in TO found in the elderly group in the present study. In addition, reduction in TO was observed regardless of colors of stimuli as the authors had hypothesized.

Meanwhile, we found no statistical difference in TC between the age groups (Figs. 2E–H), while the statistical power of the present study was estimated to be more than 80%. This finding might be consistent with previous morphological findings that the cone density in the retina shows no correlation with age, and the total number of cones is stable regardless of age. Approximately 5000 optic nerve fibers are lost every year in humans. The results of the present study suggest that such decay might mainly affect peripheral vision, but not central vision.

The present study did not make comparisons of visual fields among different colors of stimuli as described in the limitation of the study. However, of the colors of stimuli examined, the narrowing of the visual field was more evident for blue color than for other colors; for example, in comparison of TO between the elderly and the control, F-values (P-values) for blue, green, yellow, and red were $F_{1,37} = 11.1$ ($P = .002$), 5.9 (.02), 4.9 (.03), and 2.8 (.10), respectively (Fig. 2 top). A possible explanation might be that blue light is attenuated by the accumulation of yellow pigments in the denaturated lens with aging, resulting in a shift in the appearance of objects toward yellow. In addition, the age-related loss of S-cone sensitivity was greater than that of M- or L-cones, and reductions in light sensitivity are more frequently observed for blue than for red color. Thus, it is possible that the narrowing of the visual field was more evident for blue color than for other colors.

The results of the present study imply that in the elderly, color-discriminating capacity is well-preserved in the central retina while object-detecting capacity is impaired in the periphery. Diminished vision in the periphery field along with other declined physiological functions could increase risk of falling, thus increasing the risk of accidents and injuries in the elderly. The ability to detect colored signs on the floor or ground by peripheral visual field would be reduced in the elderly. For instance, at railway stations, the platform edges are marked by yellow lines to caution passengers against accidental falls. The results of the present study warn that the elderly might have difficulty in detecting the yellow signs in their peripheral visual fields which could lead to an increased risk of a fall from the platform. The present authors also infer that elderly persons might also experience difficulty in detecting traffic lights by peripheral vision while driving a car. However, the present results may also suggest that once they notice them and shift them to central vision, their recognition of the colors of the traffic lights would be as accurate as when they were young. Thus, it would be recommended that the elderly watch objects in their central visual field, and not use and rely on peripheral visual field as in their youth. Although reduced visual field could affect the activities of daily living and the activities of social life in the elderly, cautious avoidance of relying on peripheral vision could decrease risks of injuries and reduced quality of life in the elderly with reduced cognitive and psychomotor functions.

Another possibility would be the intervention to help reach wider visual fields in the elderly; for example, an application of the stochastic resonance (SR), a phenomenon in which an intermediate level of noise enhances the response of a nonlinear system to the weak input signal. The amplitude of the nonlinear response versus the input noise is typically an inverted U-like function characterized by maximal enhancement of the response at a specific noise amplitude value. The cross-modal stochastic resonance has been intensively studied by Manjarrez et al. They demonstrated that the ability to detect weak visual stimuli was significantly enhanced by a particular intermediate level of auditory noise. They also illustrated an effective tactile noise facilitated the amplitude of visual evoked potentials. Thus auditory or tactile noise could be employed in order to improve the detection of peripheral visual signals in the elderly. A possibility of new devices that enable the use of multi-sensory SR in the visuoauditory and visuotactile modalities to improve human visiomotor functions in the elderly.

This study has several limitations. First, fewer participants were enrolled in the elderly group than in the control group, and the male-to-female ratios were imbalanced between the age groups ($P = .019$, Fisher exact test). This was because we obtained more female than male volunteers in the elderly community where the study was performed. Second, possible effects of fatigue were not excluded. The present experiment with 1 eye required approximately 1 hour to conduct, which might have evoked considerable fatigue among the participants, especially in the elderly group. Third, the present study was conducted with a manual kinetic perimeter and a set of house-made color stimuli. This was because routinely used ophthalmological instruments were not designed for the purpose of the present study as described in the Materials and Methods section. Since the size of the stimuli and the contrasts against the background were fixed, possible effects of size and contrast sensitivity were not evaluated in the present study. Fourth, angular thresholds are dependent on the stimulus intensity (illuminance) of a target. Since the luminance of the 4-colored targets used were not adjusted to be with equal luminance, the present study did not analyze differences in visual fields among colors of stimuli. Fifth, the study design did not control for senile meiosis. In older individuals, pupil size becomes smaller with age. The amount of light available to the older person would likely be less given smaller pupils. With less light available to the elderly group due to senile meiosis, TO and TC may have been biased smaller relative to the controls. Sixth, the measurement was performed only once for each subject. It was reported that a kinetic perimetry study observed small test-retest variability and no learning effect. The present authors made measurements only once for each subject to avoid the possible effect of fatigue. Seventh, the findings of the present study should be interpreted with caution because it is difficult to determine whether or not the worsening of visual field parameters is due to advancing age, ocular disease progression, or a combination of both.
addition, there are some visual functions that are independent of aging such as saccadic suppression.\textsuperscript{31} Eighth, the present study did not evaluate changes in cognitive functions in the elderly. For example, visual working memory (VWM), an essential aspect of cognitive functioning, becomes compromised in older adults.\textsuperscript{32} Thus the reduced visual fields in the present study might be attributed to possible compromised VWM in the elderly. Endothelial dysfunction also results from hypertension or hyperglycemia is one of the leading risk factors for cognitive decline in older adults.\textsuperscript{33} Since the present study excluded persons with those diseases, possible effects of such endothelial-damaging pathology were not examined. Ninth, the present study included no subjects between age 50 and 69. The volunteer subjects were recruited from staff members of the college where the first author serves for the control group, and from a senior community group near the college for the elderly group. The membership eligibility of the community group was 70-year-old or older. There were no volunteers in their 50s and 60s from the college staff. Therefore, this age gap occurred merely by chance. It was reported that the decline in visual sensitivity was linear until 60s, and more rapid over 70s.\textsuperscript{15} The authors speculate that this age gap between 50 and 69 should belong to the control group rather than the elderly group, and thus this gap would not add a bias to the conclusion of the present study.

In conclusion, TO was significantly wider than TC in the control group for each color, whereas there were no significant differences between TO and TC in the elderly group. TO was significantly narrower in the elderly than in the control group, while there was no difference in TC between the 2 groups for each color examined. The narrowing of TO might reflect an age-related decline in the function of rods due to a reduction in their density in the periphery, while the unchanged TC might indicate a stable functioning of cones due to their density in the central retina being unchanged with aging.

Acknowledgments

The authors thank the volunteers for their participation in this study. The authors are grateful for the kind support of the members of the Toka Medical Skills College. The authors express sincere thanks to Dr Raymond Langley (Faculty of Welfare and Health Sciences, Oita University) for editing and Ms Kazue Ogata (Faculty of Welfare and Health Sciences, Oita University) for technical support.

Author contributions

Conceptualization: Takeshi Yada.
Data curation: Takeshi Yada.
Formal analysis: Takeshi Yada.
Project administration: Osamu Tokumaru.
Supervision: Nobuoki Eshima, Takaaki Kitano, Isao Yokoi.
Visualization: Takeshi Yada.
Writing - original draft: Takeshi Yada, Osamu Tokumaru.
Writing - review & editing: Nobuoki Eshima, Takaaki Kitano, Isao Yokoi.

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