Identification of brain regions associated with the central and peripheral visual field and applications for improving traffic safety

1. Background and goals

The perception and cognition of pedestrians appearing in the peripheral vision of drivers, and vice versa, is essential to traffic safety. Therefore, studies of cognitive processing in central and peripheral vision are urgently needed to reduce traffic accidents.

The aim of this study was to make recommendations for the realization of traffic safety by revealing the visual attributes that play important roles in human cognition and behavior.

1-1. Main study point

Three factors were the focus of this study: elderly individuals, intersections, and night-time.

Elderly individuals: the proportion of elderly individuals in fatal traffic accidents continues to increase.

Intersections: according to the study of traffic fatalities by road type, approximately half the fatalities happen at the time of crossing streets or intersections.

Night-time: the number of traffic fatalities peaks from dusk on into night-time.

The probability of traffic accidents will increase further when these factors are concurrently present.

To investigate the correlation between the three factors and human visual function, special attention was paid to peripheral vision, because proper perception and cognition of pedestrians (automobiles) in the peripheral vision by drivers, and vice versa, will definitely improve traffic safety.

The functional properties of peripheral vision in humans have been investigated from the perspective of cognitive psychology but have yet to be fully elucidated. In addition, little information is available on the central processing of visual information originating in the peripheral visual fields. In this study, we therefore performed cognitive psychological experiments to investigate dynamic vision and the effects of aging as well as neurological experiments to quantitate the cortical representation of peripheral vision using functional magnetic resonance imaging (fMRI). The properties of a wide field of view and traffic safety were also investigated.

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2. Research content

2-1. fMRI study on the physiological characteristics of a wide field of view

After developing a wide-field stimulus presentation device that operates under the MRI (high magnetic field) environment, fMRI was performed to reveal functional differences between central and peripheral vision.

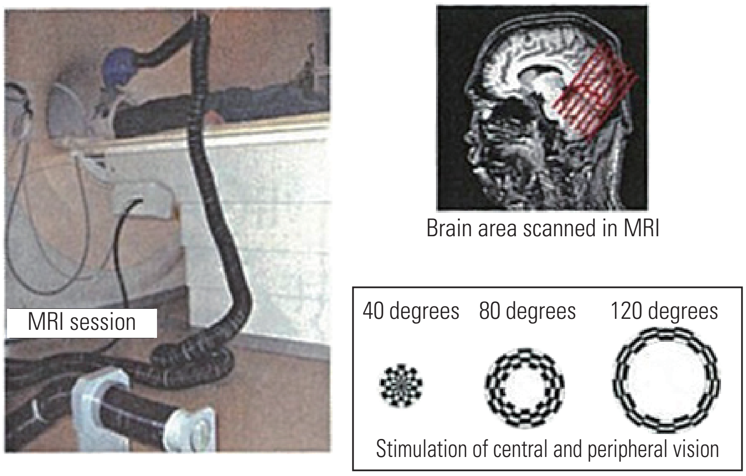

Figure 1. Imaging device and technique for cortical representation of the visual field

First, retinotopic mapping (functional mapping of the visual cortex)[1] and quantitative analysis of central and peripheral vision were performed. Conventionally, it has been possible to examine only up to 60 degrees of visual angle due to the limitations of temporal resolution in fMRI. Therefore, to perform this experiment, we developed a new stimulus presentation device that enables the mapping of up to 120 degrees of visual field. As a result, we could confirm that a diffuse area adjacent to the occipital lobe was the brain region involved in the processing of peripheral vision. Use of the device, with its wider field of visual stimulation, further revealed that this diffuse area was more extensive than previously studies have reported.

Quantitative analysis showed that the size of the brain area involved in information processing decreases as the visual field nears the far periphery. Furthermore, the study of the temporal frequency response properties of central and peripheral vision showed that the maximum response was elicited by a temporal stimulation frequency of 4 Hz when the eccentricity was 20 degrees (central visual field) (1) and by temporal frequencies of 4–8 Hz when the eccentricity was 40 degrees (2), but only small differences were observed in the responses to individual frequencies when the eccentricity was 60 degrees (peripheral visual field) (3).

2-2. Cognitive psychological study on the characteristics of wide field of view

A conventional manual device to measure dynamic visual field was automated to quantitatively analyze the dependency of dynamic visual field on brightness and color. Differences in dynamic visual field between young and elderly individuals were also measured and analyzed. Further, we modified the light

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(1) Retinotopy: Using a similar principle as in cameras, light information from an object is projected onto the retina, where it is converted into electrical signals by photoreceptors. In this process, spatial information in the retina is maintained in the visual cortex in the brain. For example, information from the center of the retina is sent to the posterior of the visual cortex, while more anterior regions of the visual cortex process information originating from more peripheral locations of the retina. Such reconstruction of spatial information in the retina by the visual cortex is called retinotopy.

source in the measurement device, which allowed us to quantitate the dependency of dynamic visual field on brightness and color, and to investigate how aging affects the dependency.

Dynamic visual field is defined as a visual range within which humans are able to discriminate a moving object. Dynamic visual field is particularly important when driving or crossing streets. In this study, the Goldmann perimeter was remodeled to be functionally flexible and more accurate. Underestimation of dynamic visual field by subjects is a serious problem, especially when studies involve fast-moving visual targets or elderly individuals with slow reaction speeds. In this study, we therefore measured the response time of subjects under different condition to correct for this underestimation.

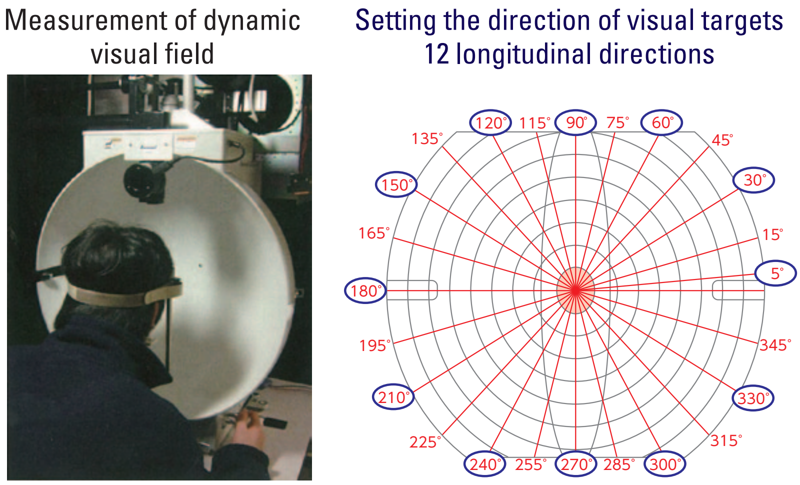

Figure 2. Development and use of a dynamic visual field measurement device

Subjects were 5 individuals aged 20–23 years, 9 individuals aged 50–64 years, 4 elderly individuals aged 65–74 years, and 4 elderly individuals aged 75–80 years. Subjects were instructed to stare at the center of the screen and push a button as soon as they notice a target moving inward from the periphery at a given constant speed. Results indicated that dynamic visual field was relatively wider in younger individuals than in elderly individuals. With regard to speed dependency, all age groups had a tendency to decrease slightly as the speed of the target increased. The visual field in elderly individuals aged 75–80 years was approximately half the visual field in individuals in their 20s, revealing a marked effect of aging. However, dynamic visual field was not lost evenly in an age-dependent manner, and dynamic visual field instead varied greatly among individuals.

2-3. Investigation of the association between wide field of view and traffic safety

We plan to apply the findings of this study to improve traffic safety and recommend the revision of road sign installation criteria and of regulation for traffic safety education aimed at elderly people.

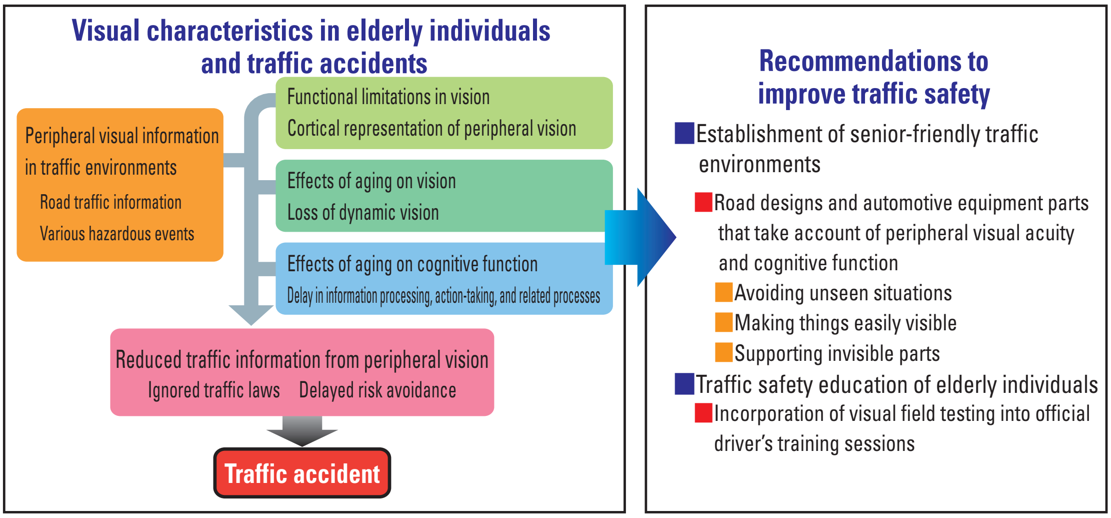

Figure 3. Recommendations to improve traffic safety based on the relation between visual characteristics in elderly individuals and traffic accidents

3. Conclusions

Through the investigation of central and peripheral vision in humans, we were able to reveal under what circumstances peripheral visual acuity was compromised. The effect of aging on dynamic visual field was substantial, particularly among elderly individuals aged 75–80 years because of severely impaired cognition of moving objects in peripheral vision.

In retinotopic mapping, the central information processing area for peripheral vision was narrow compared with central vision. Furthermore, the study of brain activity in response to temporal frequencies showed that the maximum response was elicited by a temporal stimulation frequency of 4 Hz when the eccentricity was 20 degrees (central visual field) (1) and by temporal frequencies of 4–8 Hz when the eccentricity was 40 degrees (2), but only small differences were observed in the responses to individual frequencies when the eccentricity was 60 degrees (peripheral visual field) (3).

4. Future outlook

When moving on a street (including driving), we sense and process environmental signals before taking proper actions. To act safely, it is necessary to accurately execute the 3 stages of information processing—perception, cognition, and action—and as the organ that governs these functions, the brain should be investigated to reduce traffic accidents. In this study, to recommend traffic safety measures, special attention was paid to intersections and to elderly individuals, who are highly associated with traffic accidents, to investigate the brain function involved in wide-field visual acuity and the effects of aging on dynamic vision. It is important to continue basic research with emphasis on the central mechanisms involved in perception, cognition, and action in order to reduce the number of traffic accidents in the future.