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ORIGINAL RESEARCH

Age-Related Differences in Perception of the Rotating Snakes Illusion Among Young and Older Adults with Normal Visual Acuity

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Purpose: Visual illusions are utilized to elucidate mechanism of visual information processing. For example, the Rotating Snakes illusion creates the illusory perception of motion when viewing a static image. This study investigated the difference in perception of illusory rotation between younger and older adults with normal visual acuity.

Participants and Methods: The participants included 105 younger adults (mean age: 23.7 years) and 100 older adults (mean age: 74.2 years). Each participant was presented with the Rotating Snakes illusion, then asked to respond whether they perceived the snakes to be "rotating" or "not rotating". The rate of perception of illusory rotation was compared between the two groups. To evaluate the effects of cataracts, a major age-related optical change, comparisons were also made between older participants with bilateral cataracts versus those with bilateral intraocular lens (IOL) implantation.

Results: Rotation was perceived by 100% (105/105) of participants in the younger group, but only by 16% (16/100) of participants in the older group, showing a significant difference ($p < 0.001$). Among the older adults, the IOL and cataract groups had no significant difference in the rate of those who perceived the illusion (6/54 vs 10/45, $p = 0.12$).

Conclusion: Significantly more younger adults perceived illusory motion in the Rotating Snakes illusion versus older adults. Lens opacity due to aging likely does not contribute to this phenomenon.

Keywords: visual illusion, aging, illusory motion, cataract

Introduction

In visual information processing, light signals are received by photoreceptors, converted into electrical signals in the sensory retina, and then transmitted to the visual centers of the brain. This information input from the eyes is also referred to as a bottom-up signal. Perception is brought about by the interaction of these bottom-up signals with top-down signals generated from the higher centers of the cerebrum based on memories and knowledge. However, the exact processes resulting in perception have not been clarified. Visual illusions, which are discrepancies between the physical characteristics of an object and visual perception, have long been utilized to elucidate the mechanism of visual information processing. Various illusion images have been created and studied. For instance, the Rotating Snakes illusion developed by Professor Kitaoka is a visual phenomenon that creates the illusory perception of motion when viewing a static image (Figure 1).[1,2] Various factors have been examined to explain why static images are perceived to be rotating. The perception of illusory rotation has been associated with luminance,[3–5] contrast[3–5] and color sequences[6] of the illusory image, as well as eye movements,[2] although details behind its mechanism remain obscure.

Billino et al reported age-related differences in susceptibility to the illusory perception of motion, specifically in the Rotating Snakes illusion,[7] demonstrating that older participants had a lower rate of illusory perception than younger participants. Similarly, Kitaoka also reported a significant negative correlation between age and illusion.[8] However, the cause of the age-related difference remains unclear. Aging is known to affect various stages of visual information processing. Previous studies have

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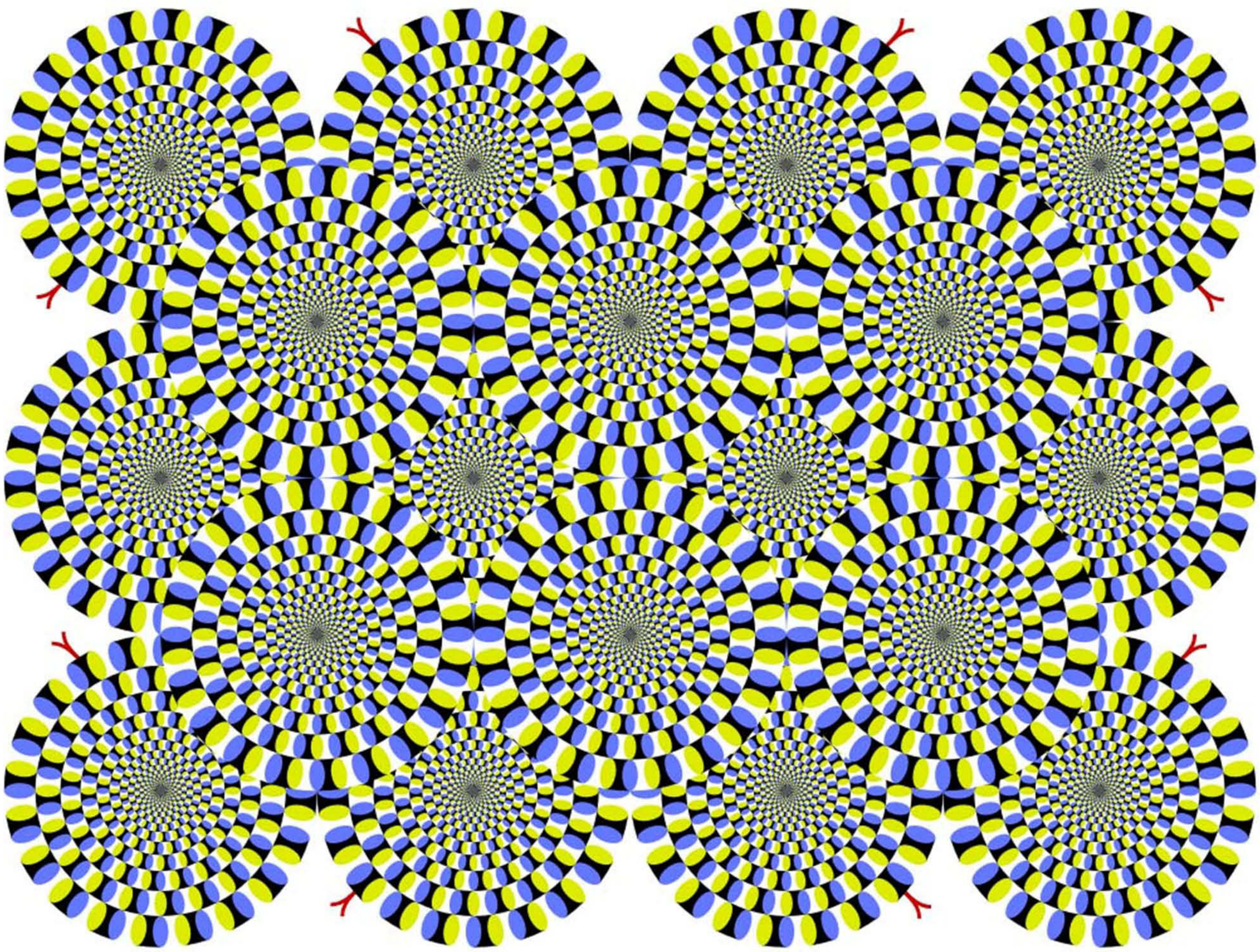

Figure 1 Rotating Snakes illusion. Circular snake-like patterns appear to rotate when viewed by some individuals. The direction of rotation is perceived in the same direction as the black–blue–white–yellow sequence.

reported age-related changes in motion perception,[9,10] temporal processing,[11] and attentional modulation[12] in older adults without overt cognitive impairment. Documented declines in the processing of dynamic visual information and the integration of local visual signals into global percepts[13] suggest that aging can alter higher-level perceptual mechanisms. Visual illusions—especially motion-based illusions—are therefore considered useful tools for probing age-related changes in visual information processing as they reflect retinal input as well as central perceptual integration.

Against this background, we examined the effects of aging on the eye, which represents the earliest stage of visual information processing.

Decreased retinal illumination, mainly caused by cataracts, is one of the main age-related optical changes that can affect visual perception.[14–16] Accordingly, we hypothesized that if reduced retinal illumination is primarily caused by cataracts, then bilateral intraocular lens (IOL) implantation for the treatment of cataracts may improve retinal illumination, thereby improving the rate of perception of illusory movement. Previously, Billino et al included participants with normal visual acuity measured binocularly, excluding those with ocular disease,[7] whereas Kitaoka did not assess visual acuity or the presence of ocular disease among the study participants.[8]

To address this knowledge gap, the present study investigated the difference in perception of illusory rotation using the Rotating Snakes illusion between younger and older individuals who underwent ophthalmic examinations. Additionally, to elucidate the effect of IOL implantation, this study compared the difference in perception of illusory rotation between older adults with untreated bilateral cataracts and those with bilateral IOL implantation. The difference between younger adults and older adults with IOL-implanted eyes was also compared.

Materials and Methods

Participants

This observational study was conducted at Aichi Medical University Hospital with ethical approval from the Institutional Review Board of Aichi Medical University. Participant recruitment and data collection were conducted between September 2023 and March 2024.

The study participants, classified into the younger and older groups, were recruited from the Department of Ophthalmology at Aichi Medical University. The inclusion criteria for the younger group were as follows: (1) aged 20–29 years, (2) best-corrected visual acuity (BCVA) of 1.0 or better in both eyes, (3) no ocular abnormalities. The inclusion criteria for the older group were as follows: (1) aged 65 years or higher, (2) BCVA of 1.0 or better in both eyes, and (3) no ocular diseases other than cataract and implanted IOL. The exclusion criterion was current or previous history of any neurological disorder, especially cognitive impairment. In the older group, cognitive impairment was estimated based on the contents of the conversations (eg, regarding lifestyle, recent changes, activities, and complaints) with the participants during the medical examinations, as well as on interviews with the family members and/or caregivers accompanying the participants.

The younger group underwent BCVA measurement and slit-lamp biomicroscopy. The older group underwent complete ophthalmologic examinations, including BCVA measurement, slit-lamp biomicroscopy and fundus examination.

The Rotating Snakes illusion (Figure 1) was presented on an iPad Pro 12.9-inch (Apple, Cupertino, CA, United States) to all participants with both eyes open positioned 30 cm from the screen under best-corrected near vision conditions.

Procedure

In the Rotating Snakes illusion, the “snakes” are sequences of bands with different colors in the sequence of black–blue–white–yellow, which is repeated in the same direction. For some individuals, this creates the illusion that the snakes are rotating. We presented the Rotating Snakes illusion without prior explanation in order to avoid any preconceived notions. Patients were asked if they had seen the image before, and if they had, then they were excluded from the analysis. The image was presented without restricting eye movement and without a time constraint.

After presenting the illusion, the examiner waited briefly for the participant to respond voluntarily, and then asked the subject, “How does it look?” If there was no comment about movement in the image, the examiner prompted, “Does it look like something is moving in the image?” The responses from subjects were categorized as “rotating” or “not rotating” based on the presence of movement, regardless of the degree of rotation. If the participant answered that there was no movement, then the result was classified as “not rotating”. However, if there was any description of movement, even without explicitly saying the exact word “rotation” in Japanese, then the result was classified as “rotating”.

Responses were compared between the older and younger groups. The older group was further subdivided into those with untreated bilateral cataracts and those with cataracts treated with bilateral IOL implantation. The rate of perception of illusory rotation was also compared between these two subgroups, as well as between the IOL group and the younger group.

Statistical Analysis

Continuous variables are expressed as the mean ± standard deviation or range, and categorical variables as frequency or proportion (percentage). Categorical variables, including the presence or absence of illusory rotation perception, were compared between groups using the chi-square test or Fisher’s exact test, as appropriate. Fisher’s exact test was applied when expected cell counts were small. Continuous variables were analyzed using Student’s *t*-test. Results with a p-value < 0.05 were considered statistically significant.

Results

This study analyzed 205 participants, all of whom satisfied the inclusion and exclusion criteria. All participants were Asians whose native language was Japanese. None of the subjects had previous experience with the Rotating Snakes illusion.

Table 1 shows the demographic and refractive status of the younger group (n = 105) and older group (n = 100). The younger group included 50 females and 55 males with a mean age of 23.7 ± 1.8 years. The older group included 61

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Table 1 Demographics and Refractive Status of the Younger versus Older Groups

	Younger Group (N =105)	Older group (N = 100)	*p*-value
Age, mean ± SD (years)	23.7± 1.8	74.2 ± 5.7	<0.001
Sex			0.075
Female, n (%)	50 (47.6)	61 (61)	
Male, n (%)	55 (52.4)	39 (39)	
Spherical equivalent, mean ± SD			
Right eye	−3.70 ± 2.30	−0.49 ± 0.89	<0.001
Left eye	−3.52 ± 2.24	−0.72 ± 1.20	<0.001

Abbreviation: SD, standard deviation.

females and 39 males with a mean age of 74.2 ± 5.7 years. The gender distribution did not differ significantly between the younger and older groups ($\chi^2(1) = 3.17$, $p = 0.075$, $\varphi = 0.12$), whereas refractive power differed significantly between the two groups ($p < 0.001$).

The illusion was perceived by 105 of 105 (100%) participants in the young group, but only by 16 of 100 (16%) participants in the older group, representing a significant difference (Fisher's exact test, $p < 0.001$) (Figure 2A).

In the older group, one subject who had untreated cataracts in one eye and IOL implantation in the other eye was excluded from further analysis. Out of these 99 older participants, 54 (55%) had bilateral IOL implantation, while 45 (45%) had bilateral untreated cataracts. Table 2 shows the demographic and refractive status of the IOL and cataract

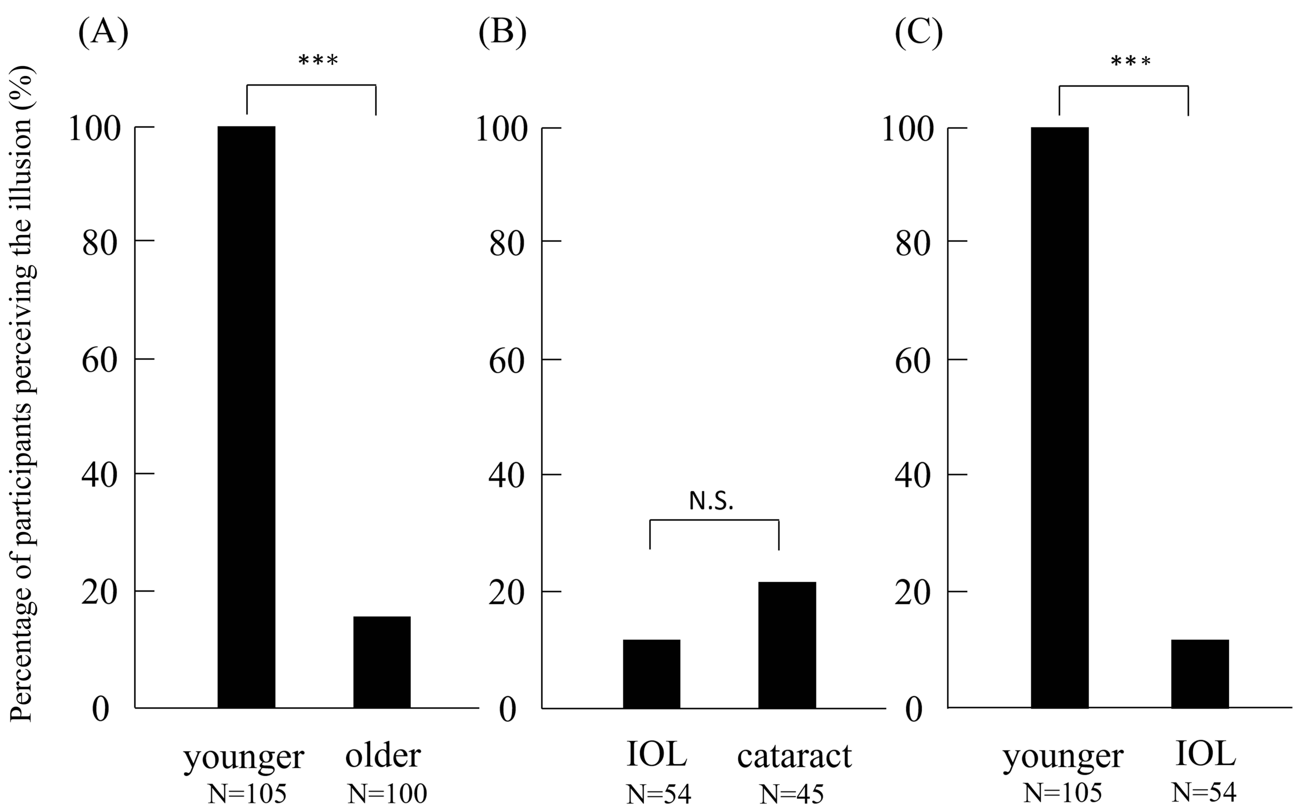

Figure 2 Comparison of the rate of perception of illusory rotation when presented with the Rotating Snakes illusion. (**A**) Comparison between participants in their 20s and participants aged 65 years or older. Younger participants perceived the rotation illusion at a significantly higher rate than older participants, ***$p < 0.001$. (**B**) Comparison between older participants with intraocular lenses (IOL) implanted in both eyes and those with cataracts in both eyes showed no significant difference ($p = 0.12$). N.S., no significant difference. (**C**) Comparison between young participants and older participants with IOL implanted in both eyes. Young participants perceived the rotation illusion at a significantly higher rate than older participants with IOL, ***$p < 0.001$.

Table 2 Demographics and Refractive Status of Older Participants with Intraocular Lens Implantation versus Untreated Cataracts

	IOL group (N = 54)	Cataract group (N = 45)	*p*-value
Age, mean ± SD (years)	75.9 ± 5.6	71.9 ± 4.7	0.001
Sex			0.14
Female, n (%)	38 (70.4)	22 (48.9)	
Male, n (%)	16 (29.6)	23 (51.1)	
Spherical equivalent, mean ± SD			
Right eye	−0.49 ± 0.89	−0.30 ± 2.45	0.32
Left eye	−0.72 ± 1.20	−0.31 ± 2.63	0.17

Abbreviation: SD, standard deviation.

subgroups. A significant difference was seen in age ($p = 0.001$). The gender distribution did not differ significantly between the IOL and cataract groups ($\chi^2(1) = 2.16$, $p = 0.14$, $\varphi = 0.22$) and in refractive status ($p > 0.05$).

All participants had single-focus lenses implanted, with yellow lenses in 45 of 54 participants and unknown type in 9 participants. The illusion was perceived by 6 of 54 (11.1%) participants in the IOL group and by 10 of 45 (22.2%) participants in the cataract group, demonstrating no significant difference ($\chi^2(1) = 2.41$, $p = 0.12$, $\varphi = 0.16$) (Figure 2B). Meanwhile, significantly fewer participants in the IOL group perceived the illusion when compared to the younger group (Fisher's exact test, $p < 0.001$) (Figure 2C).

Discussion

This study revealed that the perception of illusory rotation using the Rotating Snakes illusion was significantly higher among younger (20–29 years) versus older (≥65 years) Japanese participants, even after accounting for cataracts. This finding is in line with previous studies. Billino et al demonstrated that 100% of younger participants but only 23% of older participants in Germany perceived the Rotating Snakes illusion, similarly finding a significant difference.[7] Meanwhile, Kitaoka reported a significant negative correlation between age and the perception of illusory rotation among Japanese participants.[8] Collectively, these findings demonstrate that the low rate of perceiving illusory rotation among older individuals is a robust phenomenon that occurs regardless of race.

Billino et al hypothesized that this age-related difference is due to latent reaction time to the chromatic pattern in the image.[7] Crognale showed the differential effects of aging on the chromatic and achromatic visual pathways, revealing that increasing age was associated with a decreased response to chromatic patterns but had no effect on achromatic patterns.[17] Nevertheless, much remains unknown regarding the relationship between perception of motion illusions and color vision in different ages. Notably, humans have color constancy, which means that color vision is sufficiently accurate even in environments with diverse spectral characteristics. Kitaoka reported that the perception of illusory rotation occurs when using both grayscale and color images.[18] Meanwhile, Kobayashi et al reported that specific colors used in the illusion image influence the strength of the rotating perception.[6] However, despite the use of color images in this study, which are supposed to induce a stronger perception of illusory rotation, the perception rate in older adults was markedly low. Thus, other factors contributing to the age-related differences must be considered.

Another speculated reason is the age-related optical changes that do not occur in young people, such as lens opacity. Since lenses become cloudy or yellowish with age, transmittance in the short wavelength region of visible light (400–550 nm) is gradually lost. Cataracts also reduce retinal illumination.[14–16] Hisakata and Murakami reported that retinal illumination can influence the perception of illusory rotation, revealing that a decrease in retinal illumination resulted in a decrease in illusory rotation rate.[19] This led us to hypothesize that cataracts reduce the amount of light information entering the eye, in turn reducing rotational perception. Accordingly, we compared the rate of perception of illusory rotation between older adults with bilateral IOL implantation versus those with untreated cataracts, but no significant difference was found between the two groups. The absence of a significant difference in the perception of illusory rotation between older adults with untreated cataracts and those with IOL implantation warrants further consideration. Although cataracts are known to reduce retinal

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illumination and alter spectral transmission, our results suggest that such optical changes alone may not be sufficient to substantially influence the perception of illusory rotation in older individuals. We also compared the IOL group to the younger group to eliminate the possible influence of lens opacity, but the rate of illusory rotation remained significantly lower among older participants. Thus, despite increasing retinal illumination among older adults (ie, through IOL implantation), the perception of illusory rotation remained unchanged, suggesting that retinal illumination has only a small effect—if any—among older adults. Although refractive error differed significantly between younger and older participants, refractive differences primarily affect retinal image size and spatial frequency scaling. Given that all participants had normal or corrected-to-normal visual acuity and the pronounced age-related differences, refractive differences alone are unlikely to fully account for our results. Nevertheless, refractive status cannot be entirely excluded as a contributing factor and should be more strictly controlled in future studies. Although the cataract and IOL groups differed in age, we did not find a clear association between age and perception of illusory rotation within older participants. This finding may indicate that age-related changes in susceptibility do not progress uniformly across later life. Factors other than age, such as individual differences in visual or cognitive processing, may contribute to the observed variability among older adults. These findings suggest that age-related optical changes do not fully account for the significant difference in perception of illusory rotation between younger and older individuals. Aging is associated with gradual declines in processing speed,[11] attentional modulation,[12] and temporal integration[11] even in the absence of dementia; these cognitive functions are critical for integrating local visual signals into a coherent percept of motion. Therefore, another important area to explore involves age-related changes in perceptual mechanisms at higher levels of visual processing, which require further in-depth psychophysical investigation.

This study has several limitations. First, dementia testing was not formally done among older participants, but rather it was only estimated based on the subject's attitude and understanding, as well as interviews with family members and/or caregivers. However, since cognitive function may be associated with the perception of illusory rotation, then future studies should include a comprehensive assessment of cognitive function in older participants. Second, this study did not include tests of visual functions other than visual acuity (eg, contrast sensitivity, retinal sensitivity, color sensation, stereopsis, and pupil diameter), which may have also influenced the perception of illusory rotation especially among older adults. Further research should analyze how various visual functions contribute to the observed age-related differences in perception of illusory rotation. Nevertheless, there was an evident difference in perceptual illusory rotation between young and older participants. If perceptual illusory rotation is determined at the level of the cerebrum, then this difference may help provide insight into the mechanisms of brain aging. Studies that simulate aging in young people (eg, wearing cloudy filters to simulate cataracts) cannot replicate true aging of the brain, since it presumably functions in a way that is unique to older individuals. Thus, future studies should place a greater emphasis on older individuals, possibly also incorporating brain-modeled AI technology to investigate the mechanism of illusory motion related to the brain function of older individuals.[20]

Conclusion

In conclusion, this study involving a relatively large sample confirms a significant difference in the perception of illusory motion in the Rotating Snakes illusion between young and older individuals with normal visual acuity. Notably, this phenomenon appears to be unaffected by lens opacity due to aging. From a clinical perspective, these results suggest that age-related changes in visual perception cannot be fully assessed by standard ophthalmic measures alone, and that central perceptual or cognitive factors should be considered when evaluating visual function in older adults.

Data Sharing Statement

Data are available upon reasonable request from the corresponding author (Kyoko Fujita).

Ethical Approval and Informed Consent Statements

This study adhered to the tenets of the Declaration of Helsinki. This study involves human participants and the study protocol was approved by Aichi Medical University Institutional Review Board (approval number [2023-406]). Participants gave informed consent to participate in the study before taking part and written informed consent was obtained from participants to participate in the study.

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Disclosure

The authors report no conflicts of interest in this work.

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