

EFFECTS OF YELLOW-TINTED LENSES ON VISUAL ATTRIBUTES RELATED TO SPORTS ACTIVITIES AND DAILY LIFE IN LATE MIDDLE-AGED ADULTS

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Abstract. The purpose of this study was to clarify the effects of colored lenses on the visual performance of middle-aged people. The subjects were 19 middle-aged people with a mean age of 57.4 ± 6.0 years. Five different functional lenses were used in the experiments: colorless lenses and four colored lenses (Light-yellow, Dark-yellow, Light-gray, and Dark-gray). Using each lens type, contrast sensitivity, depth perception, hand–eye coordination, dynamic visual acuity, and visual acuity/low-contrast visual acuity were measured. Visual acuity/low-contrast visual acuity was measured under the four conditions of Evening, Evening + Glare, Day, and Day + Glare. Results showed that dynamic visual acuity and depth perception did not differ among the lens types, but hand–eye coordination measurements had a significantly shorter time with the Light-yellow and Dark-yellow lenses than the Dark-gray lenses. Low-contrast visual acuity under Evening and Evening + Glare conditions tended to be lower with the Dark lenses than the Colorless and Light-yellow lenses. The subjects rated the Yellow lenses as bright in a subjective questionnaire evaluation.

Key words: low-contrast visual acuity, contrast sensitivity, dynamic visual acuity, hand–eye coordination, sports

Introduction

Many previous studies have investigated the relationship between sports and visual performance (Christenson and Winkelstein 1988; Zwierko 2007; Zwierko et al. 2010). People who engage in sports consider visual performance to be a key attribute. Factors such as hand–eye coordination, contrast, dynamic visual acuity, and depth perception are representative components of visual performance in the context of sports activities (Stine et al. 1982; Hoffman et al. 1984; Laby et al. 2011). Individuals who engage in such activities, regardless of age, take care while playing to ensure that these aspects of visual performance are maintained. Visual performance is also regarded as important for performing daily activities.

People must consider protecting their eyes from ultraviolet and blue light rays when engaging in sports and other outdoor activities. Many people play sports for much of their life or are generally active outdoors as part of life. Functional colored lenses help avoid eye damage from many years of light stimulation. Cataracts and other eye disorders related to ultraviolet light have already been reported by McCarty and Taylor (2002). It is even feared that within the visual spectrum, short-wavelength blue light rays can cause retinal disorders (Lawwill et al. 1977; Ham et al. 1976). Moreover, the high-energy, easily scattered properties of blue light rays cause glare.

People generally wear sunglasses to protect their eyes from ultraviolet and other damaging rays. Several studies have described the sunglasses (Cooper et al. 2001; Miller 1974; Fishman 1986). Lawler et al. (2007) reported on athletes' use of sunglasses in field hockey, soccer, tennis, and other sports. Black has been probably the most commonly used lens color of sunglasses to date. Black lenses, however, may affect visual performance in certain daily activities and types of sports because they darken the field of view. Kohmura et al. (2013) reported on a study of the effects of several colors of lenses on visual performance of young adults (mean age: 21 years) in sports activities. In that study, Kohmura et al. (2013) showed that yellow-tinted lenses did not adversely affect the visual performance of young adults. Aging, however, appears to alter a variety of factors such as differences in the visual performance of young and middle-aged adults. The ways in which colored lenses affect visual performance, which is essential for sports and daily activities, have not been clarified in middle-aged adults.

A variety of colors and transmittances for functional colored lenses has been developed and marketed in recent years, and this implies much complication for the best selection of lens for many users. Yellow has gained attention for its ability to cut short-wave visible blue light rays while maintaining high luminous transmittance near 550 nm, a wavelength suited for optical sensitivity in humans. Investigators in non-sports-science fields have already evaluated and reported on the effects of yellow lenses on components of visual performance, primarily contrast sensitivity (Wolffsohn et al. 2000; Yap 1984; Kelly et al. 1984; Rieger 1992).

The purpose of this study was to characterize how the use of several types of functional colored lenses affects the visual performance of middle-aged people. Indices related to daily activities and sports were used to measure visual performance.

Methods

Participants

The subjects were 19 middle-aged people (16 men and 3 women). Their mean age was 57.4 ± 6.0 years. Sixteen of the subjects used no form of visual correction, one used contact lenses, and two used eyeglasses. The subjects were people who had no organic disorder of the eye other than ametropia.

Measures

1. Contrast sensitivity

Contrast sensitivity was measured as the ability to distinguish shades. The Sine Wave Contrast Test (Stereo Optical Co., Inc., Chicago, IL, USA) was used to measure contrast sensitivity. Contrast sensitivity was measured at the spatial frequencies of 1.5, 3, 6, 12, and 18 cycles/degree. For the test, targets of the same spatial frequency are arranged on the same lines in a chart. The subjects were asked to distinguish the direction of the patterns (left, right, or up) while viewing the chart at a distance of 3.0 m. The test evaluated how faint a target the subjects were able to distinguish.

2. Depth perception

A depth perception meter (AS-7JS1, Kowa Co., Ltd., Aichi, Japan) was used to measure depth perception. The testing apparatus contained three bars, the middle one of which moved back and forth at 50 mm/s. The two bars on either side of the moving bar were stationary. The subjects viewed these bars through a window in the testing apparatus at a distance of 2.5 m and were asked to press a button when they thought the three bars were aligned horizontally. The difference in the positions of the center bar and two side bars was measured in millimeters when the button was pressed, and the absolute value of this difference was recorded. The difference was measured three times, and the mean was calculated as the final measurement.

3. Dynamic visual acuity

Dynamic visual acuity was measured with a dynamic visual acuity meter (HI-10, Kowa Co., Ltd., Aichi, Japan). For the test, each subject was asked to determine the direction of the gap of a Landolt ring moving horizontally from left to right on a semicircular screen. The rotational speed of the Landolt ring was gradually reduced from an initial speed of 40.0 rpm. Each subject pressed a button and stated the direction immediately after determining the direction of the Landolt ring gap. When a response was correct, the rotational speed at the time the button was pressed was recorded. The size of the Landolt ring was equivalent to decimal visual acuity 0.025 (log MAR: 1.6). The direction of the gap of the Landolt ring could be up, down, left, or right and was presented in random order. The measurement was repeated until three correct responses were obtained and the mean was calculated as the final measurement. The data of a subject giving three or more incorrect responses was excluded from analysis. The sample size for dynamic visual acuity analysis only was 16.

4. Hand–eye coordination

Hand–eye coordination was measured with an AS-24 (Kowa Co., Ltd., Aichi, Japan). The panel of the test apparatus contained 120 lights that were individually illuminated in random order. Once a light was illuminated, the next light was illuminated after 1.3 s or when pressed by the subject, whichever happened first. The subjects were asked to press the lights as accurately and quickly as possible. The time required for all 120 lights to be illuminated was measured. Hand–eye coordination was measured once for each subject.

5. Visual acuity and low-contrast visual acuity

Low-contrast visual acuity was measured with a CAT-CP (NEITZ Co., Ltd., Tokyo, Japan). For the test, each subject was asked to peer into the test apparatus to determine the direction of the gap of a Landolt ring. The measurements were automatically taken. The measurement conditions were Evening, Evening + Glare, Day, and Day + Glare. The luminances of the target were 200 cd/m² in the Day condition and 10 cd/m² in the Evening condition. The intensity of the Glare was 200 lux. A visual acuity test (100% contrast) and low-contrast visual acuity test with markers having 5% and 10% contrast were performed under each condition. Measurements were performed with the dominant eye. The dominant eye was determined by having the subjects either point at an object with their index finger or place an object in a circle drawn with the hands. In cases when a subject was unable to determine the direction even at the lowest setting of the measurement apparatus (log MAR 1.3) under the 5% and 10% contrast conditions (i.e., data not obtained), the result was handled as log MAR 1.4.

6. Questionnaire

The subjects answered the questionnaire based on their subjective evaluation or impression for each question in reference to a visual analog scale. The subjects marked the location on a 100 mm straight line that corresponded with their assessment. The questionnaire was inscribed with lines without length values (millimeters) noted, and

only numbers for each question. The subjects completed the questionnaire after finishing all visual performance measurements, and the locations marked by the subjects were measured in millimeters. The questions evaluated the following five qualities: brightness (bright: maximum 100 mm, dark: minimum 0 mm), clarity (sharp: 100, blurry: 0), changes in color (not changed: 100, changed: 0), glare (no glare: 100, glare: 0), and overall impression (good: 100, bad: 0).

Procedures

Each aspect of visual performance was measured in the subjects using Colorless lenses (C) and four colored lenses: Light-yellow (LY), Dark-yellow (DY), Light-gray (LG), and Dark-gray (DG). The lenses were similar to those of the lenses used in previous study (Kohmura et al. 2013). The transmittance values for the lenses were 92.0% for the Colorless lenses, 65.2% for the Light-yellow lenses, 30.4% for the Dark-yellow lenses, 65.9% for the Light-gray lenses, and 30.2% for the Dark-gray lenses.

The lenses were used in random order, with at least 15 min rest period between each measurement. The measurements of subjects wearing eyeglasses were taken with the colored lenses worn over the glasses. A summary of the measurement procedures is given below. The subjects filled out a questionnaire after completing all measurements. The measurements were similar to those of the measurements used in previous study (Kohmura et al. 2013).

The study was conducted after all subjects had been informed of the details of the experiment and gave written consent. The study was conducted with the approval of the Research Ethics Committee of the Juntendo University School of Health and Sports Science.

Statistical Analysis

One-way repeated measures analysis of variance (ANOVA) was used to analyze depth perception, hand–eye coordination, visual acuity, and the questionnaire results. Two-way repeated measures ANOVA was used to analyze contrast sensitivity and low-contrast visual acuity. The Bonferroni correction was used for multiple comparisons. The level of statistical significance was set at $p < 0.05$.

Results

Visual performance measurement results.

The measurement results are shown in Table 1 and Figures 1 and 2.

Table 1. Mean and standard deviation of visual performance with each of lenses

	Yellow			Gray	
	colorless	light	dark	light	dark
Dynamic visual acuity (rpm)	29.5 (7.6)	28.8 (8.1)	28.2 (8.5)	30.2 (7.0)	28.8 (8.1)
Depth perception (mm)	16.5 (13.7)	22.1 (20.1)	20.1 (19.7)	19.9 (16.8)	21.7 (22.1)
Eye–hand coordination (sec)	95.8 (9.4)	95.6 (9.9)	95.4 (8.9)	96.7 (9.9)	98.9 (9.3)
Visual acuity (log MAR)					
Evening	0.30 (0.23)	0.25 (0.23)	0.36 (0.18)	0.31 (0.21)	0.38 (0.23)
Evening + Glare	0.29 (0.20)	0.29 (0.18)	0.35 (0.18)	0.30 (0.21)	0.41 (0.20)
Day	0.08 (0.17)	0.16 (0.23)	0.18 (0.23)	0.16 (0.23)	0.19 (0.17)
Day + Glare	0.13 (0.22)	0.22 (0.24)	0.21 (0.25)	0.18 (0.23)	0.21 (0.22)

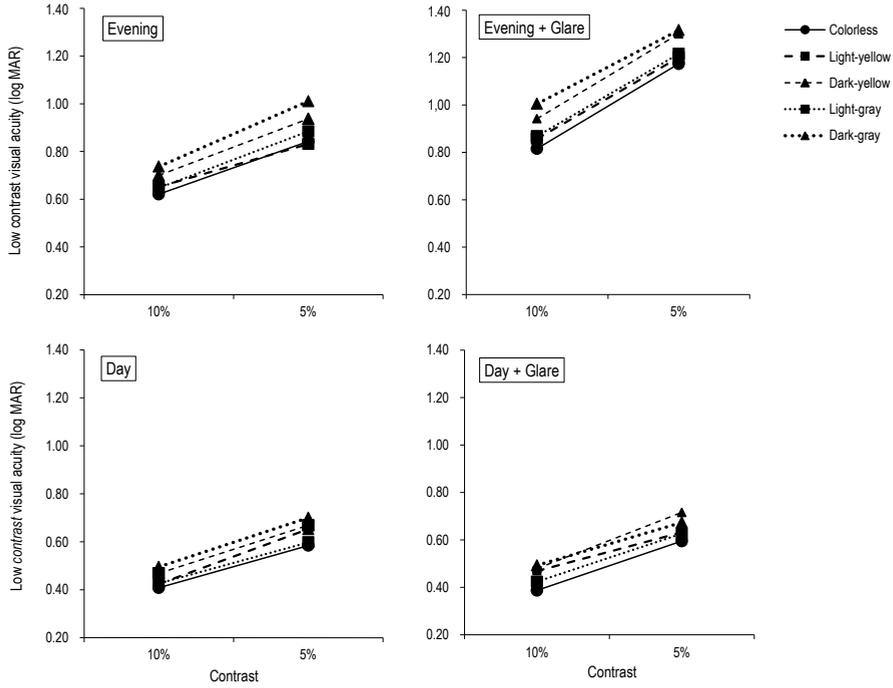


Figure 1. Measurements results for low-contrast visual acuity are shown

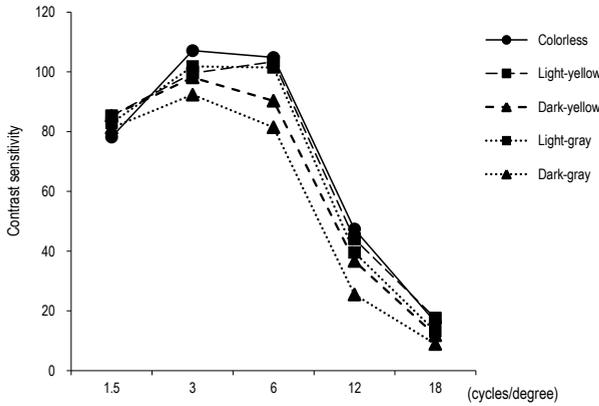


Figure 2. Means of contrast sensitivity with each of the lenses are shown

For hand-eye coordination, the ANOVA results were significant at $p < 0.05$ ($F = 3.57$, $p = 0.01$), and the results of multiple comparisons showed a significant difference between Light-yellow and Dark-gray ($p = 0.01$) and Dark-yellow and Dark-gray ($p = 0.02$) at $p < 0.05$. For visual acuity, the ANOVA results were significant for the Evening

condition at $p < 0.05$ ($F = 2.99$, $p = 0.02$). For the Evening + Glare condition, the ANOVA results were significant at $p < 0.01$ ($F = 4.14$, $p = 0.00$), and there was a significant difference between Colorless and Dark-gray at $p < 0.05$ ($p = 0.05$). For the Day condition and Day + Glare condition, visual acuity was not significantly different. No significant differences were noted for dynamic visual acuity or depth perception.

For contrast sensitivity, the interaction was not significant, and the main effects of lens and spatial frequency were both significant at $p < 0.01$ (lens: $F = 3.99$, $p = 0.01$, spatial frequency $F = 78.49$, $p = 0.00$).

For low-contrast visual acuity, the interaction was not significant, and the main effect of contrast was significant at $p < 0.01$ under all conditions (Day: $F = 257.81$, $p = 0.00$, Day + Glare: $F = 216.01$, $p = 0.00$, Evening: $F = 319.91$, $p = 0.00$, Evening + Glare: $F = 231.71$, $p = 0.00$).

Under the Evening condition, the main effect of lens was significant at $p < 0.01$ ($F = 12.36$, $p = 0.00$), and the results of multiple comparisons showed a significant difference between Colorless and Dark-gray ($p = 0.00$) and Light-yellow and Dark-gray ($p = 0.00$) at $p < 0.01$. Moreover, there was a significant difference between Colorless and Dark-yellow ($p = 0.01$) and Light-yellow and Dark-yellow ($p = 0.03$) at $p < 0.05$. There was also a significant difference between Light-gray and Dark-gray at $p < 0.01$ ($p = 0.00$).

Under the Evening + Glare condition, the main effect of lens was significant at $p < 0.01$ ($F = 14.90$, $p = 0.00$), and the results of multiple comparisons showed Colorless to be significantly different from both Dark-yellow ($p = 0.00$) and Dark-gray ($p = 0.00$) at $p < 0.01$. Light-yellow was significantly different from both Dark-yellow ($p = 0.00$) and Dark-gray ($p = 0.00$) at $p < 0.01$. There was also a significant difference between Light-gray and Dark-gray at $p < 0.05$ ($p = 0.01$).

Under the Day condition, the main effect of lens was significant at $p < 0.01$ ($F = 4.38$, $p = 0.00$). Under the Day + Glare condition, the main effect of lens was significant at $p < 0.01$ ($F = 4.99$, $p = 0.00$), and there were significant differences between Colorless and Dark-yellow at $p < 0.01$ ($p = 0.00$) and Colorless and Dark-gray at $p < 0.05$ ($p = 0.02$).

Questionnaire results

The Questionnaire results are shown in Figure 3.

The results of one-way ANOVA were significant at $p < 0.01$ for all questions (brightness: $F = 28.85$, $p = 0.00$, clarity: $F = 5.77$, $p = 0.01$, color: $F = 35.02$, $p = 0.00$, glare: $F = 11.66$, $p = 0.00$, overall: $F = 16.17$, $p = 0.00$). The results of multiple comparisons revealed Colorless to be significantly different from Light-gray ($p = 0.00$) and Dark-gray ($p = 0.00$) at $p < 0.01$ for the questions related to brightness. Light-yellow was significantly different from Dark-yellow ($p = 0.00$), Light-gray ($p = 0.00$), and Dark-gray ($p = 0.00$) at $p < 0.01$. Dark-yellow was significantly different from Dark-gray at $p < 0.05$ ($p = 0.01$). Light-gray was significantly different from Dark-gray at $p < 0.01$ ($p = 0.00$).

Colorless was significantly different from Dark-gray ($p = 0.00$) at $p < 0.01$ for the questions related to clarity. Light-yellow was significantly different from both Dark-yellow at $p < 0.05$ ($p = 0.02$) and Dark-gray at $p < 0.01$ ($p = 0.01$). Light-gray was significantly different from Dark-gray at $p < 0.01$ ($p = 0.00$).

For the questions related to change in color, Light-yellow was not significantly different from Dark-yellow, but a significant difference was noted for all other combinations at $p < 0.01$. Only the combination of Colorless and Light-gray was significant at $p < 0.05$ ($p = 0.03$).

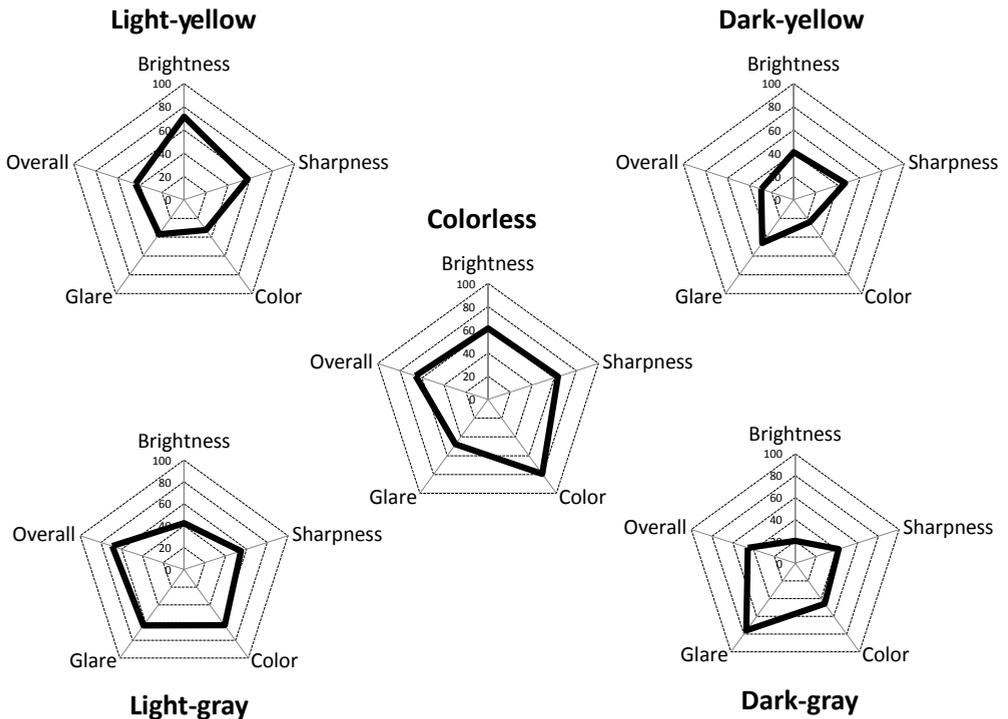


Figure 3. Questionnaire results (Score)

Colorless was significantly different from Light-gray ($p = 0.01$) at $p < 0.05$ and Dark-gray ($p = 0.00$) at $p < 0.01$ for the questions related to glare. Light-yellow was significantly different from both Light-gray at $p < 0.05$ ($p = 0.01$) and Dark-gray at $p < 0.01$ ($p = 0.00$). Dark-yellow was significantly different from Dark-gray at $p < 0.01$ ($p = 0.00$). Light-gray was significantly different from Dark-gray at $p < 0.05$ ($p = 0.02$).

Colorless was significantly different from Dark-yellow ($p = 0.00$) at $p < 0.01$ for the questions related to overall impression. Light-yellow was significantly different from both Dark-yellow at $p < 0.01$ ($p = 0.00$) and Light-gray at $p < 0.05$ ($p = 0.02$). Dark-yellow was significantly different from both Light-gray at $p < 0.01$ ($p = 0.00$) and Dark-gray at $p < 0.05$ ($p = 0.01$). Light-gray was significantly different from Dark-gray at $p < 0.01$ ($p = 0.00$).

Discussion

The lenses tested did not differ significantly with regard to dynamic visual acuity or depth perception. It is likely that the effects of lens color and transmittance are small in cases like the dynamic visual acuity test, which required the subjects to analyze a target in the central fovea, and in cases like the depth perception test, in which the subjects were asked to match the distances between three bars. In these situations, the differences among the lenses appeared to be small in the present experiment, as they were revealed to be similar to the results of previous

study in young adults (Kohmura et al. 2013). The adverse effects of the lenses used in this study in middle-aged people also appear to be minimal with regard to these visual performances in sports and daily activities.

However, hand–eye coordination measurements had significantly shorter times with the Light-yellow and Dark-yellow lenses than the Dark-gray lenses. Shorter test times indicated better assessment, or an ability to press lights quickly and accurately, because the test measured the time required for 120 lights to illuminate. The Dark-gray condition appeared to have an effect when repeatedly performing the task of accurately pressing illuminated lights found in the peripheral vision. The use of Dark-gray and similar lenses may therefore not produce uniformly favorable results in sports requiring quick and accurate judgments of, and response to, the athlete's surroundings. The significant differences noted for the yellow lenses may be attributable to the ability of yellow lenses to limit the passage of short-wavelength visual light while maintaining the transmittance of long-wavelength light, which has high relative luminosity. The ability of yellow lenses to make objects appear brighter and clearer may have also contributed to these results. Previous research also reported on the effect on brightness of yellow lenses (Kelly 1990; Chung and Pease 1999).

The above findings largely agree with the results of previous study in young adults (Kohmura et al. 2013). In contrast, the findings on low-contrast visual acuity showed significant differences in more items. Although significant differences were seen between some lenses under the light (Day) condition, many significant differences were noted between the Colorless/Light-yellow lenses and dark lenses under the Evening condition. The use of Light-yellow and Colorless lenses tended to produce higher visual acuity measurements than even the dark lenses. Differences were noted between the Colorless lenses and dark lenses in the young adults, but the additional differences between the Light-yellow lenses and dark lenses in many areas of measurement in the present study in middle-aged people were remarkable. Values for visual acuity are expected to decrease substantially with the low contrast, difficult-to-see targets under darker conditions, but the use of Light-yellow lenses appears to produce low-contrast visual acuity results comparable to those for the Colorless lenses. As the environment is not necessarily bright nor the contrast between objects clear in daily activities and sports, the use of Light-yellow and similar lenses may produce satisfactory results under various conditions and environments.

The questionnaire results largely agreed with the results of the questionnaires completed by young adults in previous study. Colorless and Light-yellow lenses were rated bright and Dark-gray lenses were rated dark in the questions about brightness. The Dark-gray lenses were rated more poorly than the Colorless, Light-yellow, and Light-gray lenses in the questions about clarity. On the questions about changes in color perception, the Light-yellow and Dark-yellow lenses were not significantly different, while the other lenses were rated as producing a significantly different change in color perception. The middle-aged subjects indicated that they could sense that yellow lenses changed the color. Previous studies (De Fez et al. 2002; Hovis et al. 1989) similarly reported on the effects that yellow lenses have on color perception. As mentioned, a number of advantages have been reported for yellow lenses. However, the change in color perception caused by using yellow lenses is a drawback that must be considered. Some results related to glare differed from those noted by the young adults. The young adults (Kohmura et al. 2013) reported that the Colorless lenses produced the greatest glare, while the middle-aged subjects in this study found the Light-yellow lenses produced the greatest glare. As the Light-yellow lenses were also rated highest in terms of brightness, the subjects may have used similar standards to evaluate brightness and glare or may have been more susceptible to glare than the young adults. Although clarifying causes such as these is difficult, the fact

that middle-aged people subjectively perceive greater glare in association with light-yellow lenses than colorless lenses bears acknowledging.

The above questionnaire results suggest that, like the young adults, the middle-aged subjects tended to rate the darker colors more poorly on questions not related to glare, which indicates that light-colored lenses are viewed favorably. It is also likely that middle-aged subjects are accustomed to black lenses. This appears to mean they are likely unfamiliar with the changes in color perception produced by yellow lenses. In order to convince others to use yellow lenses, it is important to properly convey both the strengths and weaknesses of this lens color to the user. Previous research has similarly reported that yellow lenses affect color perception (De Fez et al. 2002; Hovis et al. 1989). Other researchers have also started to investigate the effects of different color lenses (Lee et al. 2002). Thus, future studies should investigate which types of lenses are suited for which situations, factoring in differences due to age.

Many of the measurements in this study differed to a certain degree from the visual performance data for young adults (Kohmura et al. 2013). Visual performance also probably decreases with age. The differences appeared to be most substantial particularly for depth perception, hand–eye coordination, and other faculties particularly relevant to sports. Low target frequencies in the contrast sensitivity test did not produce appreciable differences, but the middle-aged subjects had lower scores when the frequency was high. However, the difference between young and middle-aged adults in low-contrast visual acuity appeared small, which indicated that there are cases where the effect of increased age differed depending on the visual performance attribute. Nevertheless, further research is needed to validate these hypotheses.

The results of the present study indicated, as in the young adults in previous study, that contrast-related performance was more readily affected by the use of dark lenses. Under evening and cloudy conditions, it is possible that light-yellow lenses can be used without adversely affecting visual performance. Lens color probably has minimal effect on visual performance when directing the line of sight to follow objects or determine distance. Dark-gray lenses, however, may have an effect on tasks requiring the user to identify and accurately and promptly react to objects in the peripheral vision, as well as their repetition. Dark lenses therefore probably have certain effects on daily activities and sports. In the subjective opinions of the subjects, as assessed by the questionnaire, relatively high ratings were given to the Light-gray lenses, a color which is both light, and to which they were accustomed in black lenses. It was expected that middle-aged people, like young adults, would feel no significant discomfort towards, and would be accustomed to, black lenses. They may also be unaccustomed to the color perception changes and sense of brightness associated with yellow lenses.

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