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Pupillary Responses and Chrominance Components in Natural Viewing Conditions

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Purpose: This study aimed to provide a basis for the functional relationship between chrominance components and pupillary responses under natural viewing conditions. **Methods:** The pupil data for twelve subjects with normal vision were collected by an eye-tracker when they were watching a 45-minute music video, and analyzed with respect to its chrominance components such as hue, saturation and lightness. **Results:** The pupillometric results show that mydriasis and miosis had similar frequency and amplitude. The count of hues had positive relationships between the amplitude of pupillary responses, and such relationships are universal features of red and yellow amongst the hues. While the frequency and amplitude of miosis did not show any significant relationships with both levels of saturation and lightness, those of mydriasis were positively and negatively related to saturation and lightness respectively. **Conclusions:** Chrominance components are functionally more related to mydriasis than to miosis.

Key words: Pupil, Mydriasis, Miosis, Chrominance, Saturation, Lightness

INTRODUCTION

Pupils react to light. Pupillary responses are determined by a balanced combination with both sphincter and dilator pupillae muscles, and are categorized as either mydriasis or miosis. Mydriasis is a sympathetic reaction to induce a larger pupil by stimulating dilator pupillae muscles in order to let more light into the eye where an insufficient amount of ambient light is present, and miosis as a parasympathetic reaction leads to a decrease in pupil diameter by stimulating iris sphincter pupillae muscles for maximizing light influx where an excessive amount of ambient light is present.[1,2] Human eyes are sensitive to visible light ranging from 400 to 700 nanometer of the electromagnetic spectrum.[3] The optic nerve converted by retinal ganglion cells finally synapses to the pretectal nuclei of the midbrain for the autonomic nerve reflex.[4,5] Specifically, a dominant pupillary response is instantaneously controlled by the autonomic nervous system, and the other part of the responses is induced by visual perception in the central nervous system. Such afferent pathways inversely innervate the iris sphincter or dilator pupillae via the oculomotor nerve.[5,6]

Many previous studies have concentrated on luminance and contrast levels in order to examine the pupillary responses according to the intensity of light. Studies conducted by Campbell and Gregory[7] and Woodhouse and Campbell[8] primarily reported that an increase of luminance results in miosis with a tendency to decrease in the contrast threshold, indicating that miosis in accordance with the luminance levels is a visual response to optimize vision. Along with the extension of their findings, a recent study demonstrated further scientific evidence that there is a linear proportional relation between the dispersion of luminance and miosis as well as the levels of luminance.[9] Further, Wang and Munoz[10] demonstrated that there is a trend of increasing both amplitude and velocity of mydriasis in line with an increment of stimulus contrast or a decrement of background luminance levels. Overall, perception of both luminance and contrast through the magno-cellular pathway is intimately involved in the pupillary responses.

However, the potential of involvement of color perception via parvo-cellular pathway in the pupillary responses has been

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highlighted. Several studies reported that the diameter of pupils can be modified by color changes.[11-15] In particular, miosis tends to be more reactive to blue wavelengths than to the other color spectrum in individuals with normal color vision.[13,16-19] It thus appears that pupillary responses are not exclusively responsive to luminance or contrast.

The previous studies of pupillary responses related to colors have been paid attention to orienting pupillary responses happened in a moment with a static visual stimulus. Now that momentary pupillary responses are hardly detectable with naked eye, such a method of investigation using a static visual stimulus for a short time is practical to theorize. Nonetheless, it is likely to be limited for the findings from the investigative method to apply pupillary responses to dynamic visual stimuli in our daily life. In addition, no previous studies have attempted to use visual stimuli that are common in our everyday life. This study therefore aims at investigating the change patterns of pupillary responses in accordance with a color video for a prolonged period of time, and at analyzing chrominance components of the video with multiple breakpoints of time, and finally at evaluating the association between the patterns of pupillary responses and chrominance components.

This study has several distinctions from the previous studies. Firstly, music videos commonly broadcasted in a TV were used as colored visual stimuli. Secondly, while the previous studies usually repeated to show a series of brief visual stimuli, music videos used in this study were given to the research participants for 45 minutes without any repetitions. Thirdly, for the analysis of chrominance components of the video, average hue, saturation and lightness in all pixels were measured per second. Fourthly, pupillary responses were categorized as either mydriasis or miosis by calculating differences in pupil sizes between post-fixation and pre-fixation, and their average frequency and amplitude were calculated per second as well. Lastly, both frequency and amplitude of the pupillary responses were categorized as three levels (low, medium, high) and examined an association with chrominance components.

SUBJECTS AND METHODS

1. Participants

Twelve participants (aged 31±17.57 years, range 15-60 years) were recruited for this study. Amongst them, five were adolescents (less than 20 years), three participants were young adults (20-29 years), and four were older adults (more than 40 years). All subjects voluntarily gave written informed consent. The experimental procedure was approved by the Institutional Review Board of Hanyang University, and adhered to the tenets of the Declaration of Helsinki. All participants had normal visual acuity (best-corrected visual acuity of 6/7.5 better) and normal color vision without any history of vision threatening disorders.

2. Apparatus

An eye tracking system (SMI RED 500 system, SensoMotoric Instruments GmbH, Teltow, Germany) was used to measure pupil diameter. A remote infrared sensor was located approximately 60 cm away from the participants without any interruption of their visual fields, and utilized to monitor and measure the pupil diameter with 60 Hz sampling rate in accordance with each fixation. The fixation-based measurement of pupil diameter is applicable in this study, since a recent study conducted by Privitera and colleagues[20] demonstrates that any saccadic movements of the eyes do not really influence the pupil diameter regardless of the size of saccades. A 54.6 inch curved 4K LED TV with a maximum resolution of 3840 × 2160 was connected to the eye tracking system.

3. Videos

Twelve different music videos with full HD resolution (1920 × 1080) and 24 frames per second were recorded a single 45-minute AVI format to utilize in the eye-tracking system (Fig. 1). All audio elements of the videos were included.

4. Video analyzer

A video analysis program using C++, MFC and OpenCV 2.4.5. was coded to measure HSL (hue, saturation, lightness) composition in a color space, since HSL is most likely to reflect the way that humans perceive colors.[21] Hue denotes color, ranging from 0° to 360°, and was classified into the six-color gamut: red (330~29°), yellow (30~89°), green (90~149°), cyan (150~209°), blue (210~269°), magenta (270~329°). Saturation denotes the purity of colors, and lightness refers to the lightness of colors. Both saturation and lightness levels range from 0 to 1.

5. Viewing conditions

Ambient illumination in the experiment room main-

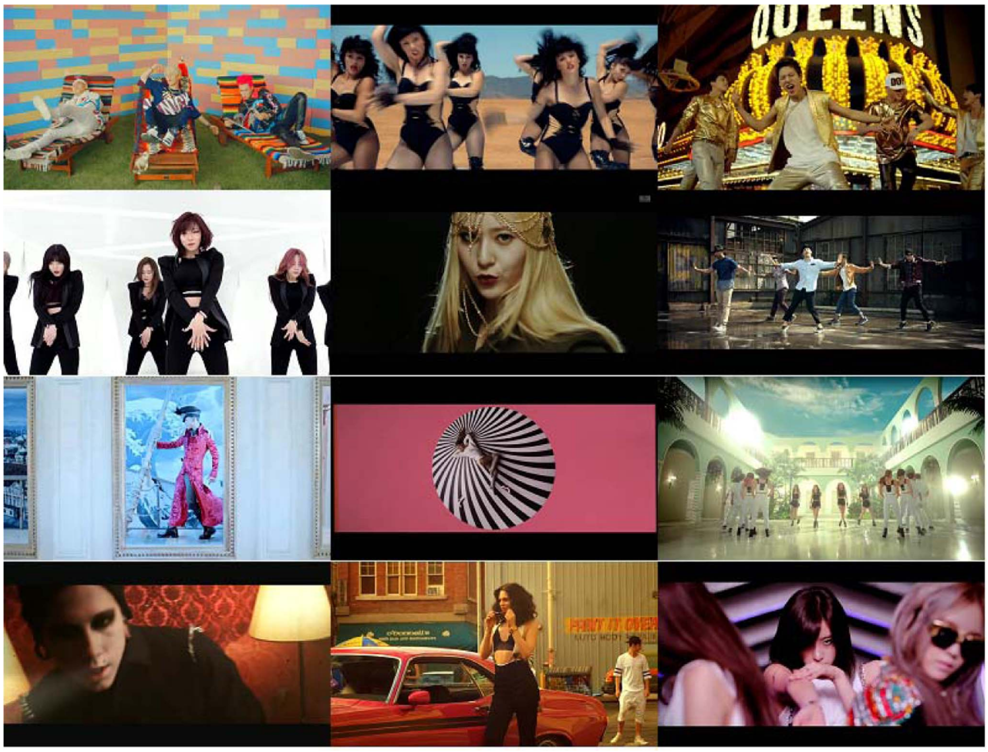

Fig. 1. Example frames of the music video used in this study.

tained 200 lx at the eye level of the participants, followed by a recommended illuminance of KS-3011 for the average Korean living room.[22] Viewing distance was 2.1 meters from the display since the viewing distance for minimizing visual fatigue to screen height is 3:1.[23] Display luminance was measured by ANSI lumens,[24] and set to average 300 nit.

6. Experimental procedure

Each participant started with a quick calibration procedure. When their fixations to the reference points were not constantly satisfactory, the calibration procedure was repeated until satisfactory fixations are obtained. After the calibration procedure, the music video was commenced to play and the pupil diameter was simultaneously measured and recorded by the eye-tracker system. A chinrest was not used due to minimizing physical discomfort, and the participants had to keep awake without a word. While the participants watched the video, a researcher always monitored a tracking data to minimize the tracking loss.

7. Data synthesis and statistical analysis

The SMI BeGaze eye-tracking analysis software provides raw pupil diameter at each fixation. The pupil diameters of both eyes which were measured at the same time only were extracted and averaged for the statistical analysis. Any pupillary data at each fixation having a different measurement time between the eyes were filtered out to minimize the confounding effect. The selected data of pupil diameter were classified into two pupillary responses by the amplitude of pupil diameters at between post-fixation and pre-fixation: mydriasis (>0 mm) and miosis (<0 mm). Based on the processed data, we counted average frequency of each response per second, and averaged the amplitude of each response. Now that a measurement method of the pupil diameter in the eye-tracker is based on fixation, i.e. averaging the pupil diameter on every fixation, an association between chrominance components and the pupillary responses can be hardly examined. To deal with this limitation, this study was to investigate an association between chrominance components and the patterns of the pupillary responses by categorizing them into the following three levels according to the 33rd and 66th percentiles for each frequency and amplitude: low (less then 33rd percentile), medium (33rd to 65th percentile), and high (over 66th percentile).

The video analyzer provides the mean hue, saturation and lightness per second. We counted a total number of each hue, and directly utilized the raw data of saturation and lightness measured per second. Now that the wide scope of hue was limited to investigate a dependence of the pupillary responses on it, this study used the six-color gamut classified by the video analyzer for statistical analyses.

All statistical analyses were performed using IBM SPSS statistics 21 (SPSS Inc., Chicage, USA). We conducted ordinal regression with the logit link function in order to examine the association between the chrominance components and the pupillary responses. The dependent variables were categories of frequency and amplitude of each pupillary response, and the three chrominance components were considered as the independent variables.

RESULTS AND DISCUSSIONS

The major results for both frequency and amplitude of each pupillary response are shown in Table 1. Overall, both mydriasis and miosis were averagely occurred more than once in one second, and their amplitudes were 0.15 mm on average. For the ordinal regression analysis, each pupillary response were categorized into three levels according to the trisection of their own data (Table 1).

As a result of a total count of 2697 average hues measured per second (Fig. 2), the most frequently used hue was yellow (n = 1018, 37.7%), followed by green (n = 654, 24.2%), cyan (n = 501, 18.8%), blue (n = 265, 9.8%), red (n = 163, 6.0%), and magenta (n = 96, 3.6%). The level of saturation was a mean of 0.32 (SD = 0.19, range 0.0 to 0.98) and that of lightness was a mean of 0.32 (SD = 0.20, range 0.0 to 0.96).

More specifically, the frequencies of the level of saturation were not normally distributed (Fig. 2). The level of saturation was skewed toward the relatively lower level in red (Mdn = 0.06, Skewness = 3.19±0.19, Kurtosis=9.44±0.38) and yellow (Mdn = 0.16, Skewness = 1.41±0.08, Kurtosis =

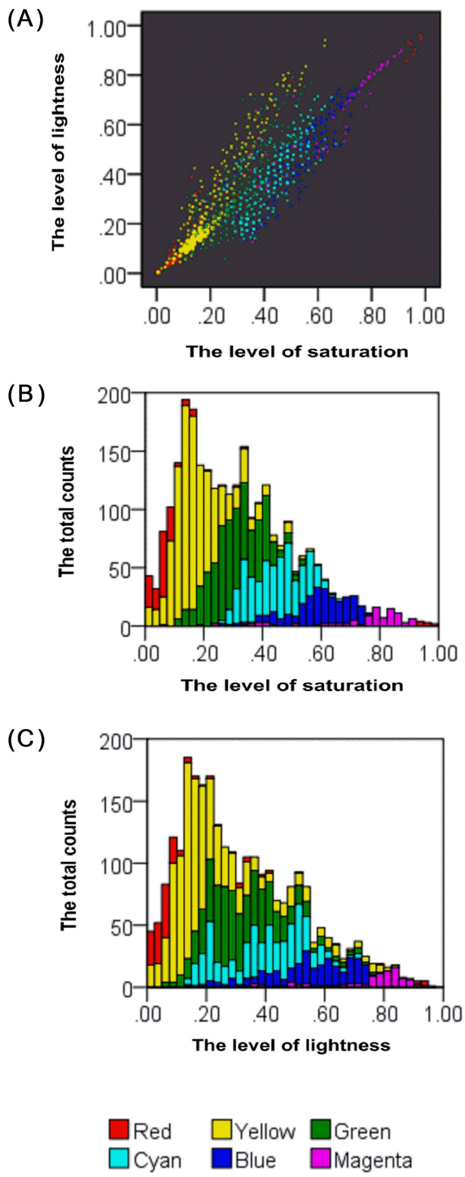

Fig. 2. Summary of chrominance components. (A) Distribution of hues according to the levels of saturation and lightness, (B) Histogram of the level of saturation, (C) Histogram of the level of lightness.

Table 1. Summary of pupillary responses

Pupillary responses		Mean±SD	Categories[a]		
			Low	Medium	High
Frequency (counts/sec)	Mydriasis	1.20±0.40	0.00 – 0.99	1.00 – 1.35	1.36 – 3.45
	Miosis	1.11±0.41	0.00 – 0.90	0.91 – 1.26	1.27 – 2.82
Amplitude (mm)	Mydriasis	0.15±0.06	0.02 – 0.11	0.12 – 0.15	0.16 – 0.51
	Miosis	0.15±0.07	0.00 – 0.10	0.11 – 0.16	0.17 – 0.68

[a]Reference points are the 33rd and 66th percentiles of each response: Low (less then 33rd percentile), Medium (33rd to 65th percentile), High (over 66th percentile).

2.90±0.15). On the other hand, both green and cyan were condensed into the medium level of saturation (Mdn = 0.30, Skewness = 0.15±0.10, Kurtosis = −0.18±0.19; Mdn = 0.45, Skewness = 0.04±0.11, Kurtosis = −0.89±0.22; respectively). Relatively high level of saturation were dominantly frequent in blue (Mdn = 0.60, Skewness = −0.90±0.15, Kurtosis = 0.93± 0.30) and magenta (Mdn = 0.79, Skewness = −1.54±0.25, Kurtosis = 1.48±0.49).

While the level of lightness of the videos had some similarities, different patterns of the frequency distribution of the level of lightness were still found (Fig. 2). Deviations towards the lower level of lightness were shown in red (Mdn = 0.06, Skewness = 2.69±0.19, Kurtosis = 6.52±0.38), yellow (Mdn = 0.17, Skewness = 1.80±0.08, Kurtosis = 3.08±0.15), and green (Mdn = 0.30, Skewness = 0.84±0.10, Kurtosis = 0.86±0.19). Further, the frequencies of both cyan and blue were largely concentrated in the medium level of lightness (Mdn = 0.40, Skewness = −0.06±0.11, Kurtosis = −0.92±0.22; Mdn = 0.56, Skewness = −0.68±0.15, Kurtosis = −0.21±0.30; respectively). Lastly, magenta was the only color having a bias towards the higher level of lightness (Mdn = 0.79, Skewness = −1.44±0.25, Kurtosis = 1.49±0.49).

The results of ordinal logistic regression analysis to examine any relationships between the exposure of chrominance components and the frequency of each pupillary response are given in Table 2. First, for the frequency of mydriasis, its significant predictors were the level of saturation with an odds ratio of 31.85 (95%CI, 7.86 to 129.02), Wald $\chi^2(1) = 23.52$, p<.001, and the level of lightness with an odds ratio of 0.14 (95%CI, 0.05 to 0.36), Wald $\chi^2(1) = 16.19$, p<.001. By considering the range of both levels, a 0.1 unit increase in the level of saturation was associated with a 41% increase in a possibility to fall upon a higher category for the frequency of mydriasis, and the likelihood of belonging to its higher category decreased by 18% with a 0.1 unit increase in the level of lightness. On the other hand, any hues were not significantly associated with the frequency of mydriasis. Second, any chrominance components did not have significant associations with the frequency of miosis.

As shown in Table 3, the outcomes of ordinal logistic regression analysis for the amplitude of pupillary responses were distinct from that for the frequency of pupillary responses. First, the most important predictor for the amplitude of mydriasis was the level of saturation with an odds ratio of 10.91 (95%CI, 2.39 to 49.90), Wald $\chi^2(1) = 9.47$, p = .002.

Table 2. Ordinal logistic regression to assess the association between the frequency of pupillary responses and chrominance components

Response	Parameters	Estimate	SE	Wald χ^2	df	OR	95% CI for Exp(ß)	Sig.
Mydriasis	Hues[a]							
	Red	−0.24	0.34	0.51	1	0.79	0.41−1.52	.78
	Yellow	−0.32	0.30	1.12	1	0.73	0.41−1.31	.29
	Green	−0.23	0.27	0.73	1	0.79	0.47−1.35	.39
	Cyan	−0.35	0.24	2.16	1	0.70	0.44−1.13	.14
	Blue	−0.23	0.24	0.89	1	0.79	0.50−1.27	.34
	Saturation	3.46	0.71	23.52	1	31.85	7.86−129.02	<.001
	Lightness	−1.97	0.49	16.19	1	0.14	0.05−0.36	<.001
Miosis	Hues[a]							
	Red	0.01	0.35	0.00	1	1.01	0.51−1.99	.99
	Yellow	−0.26	0.30	0.76	1	0.77	0.42−1.39	.39
	Green	−0.19	0.27	0.47	1	0.83	0.49−1.42	.49
	Cyan	0.08	0.24	0.12	1	1.08	0.68−1.73	.73
	Blue	0.09	0.24	0.14	1	1.09	0.68−1.73	.71
	Saturation	0.70	0.75	0.87	1	2.01	0.46−8.67	.35
	Lightness	−0.52	0.52	1.01	1	0.59	0.22−1.63	.32

Note. SE=standard error; df=degree of freedom; CI=confidence interval; OR=odds ratios; Sig=significant level at 0.05; [a]Reference is magenta

Table 3. Ordinal logistic regression to assess the association between the amplitude of pupillary responses and chrominance components

Response	Parameters	Estimate	SE	Wald χ^2	df	OR	95% CI for Exp(ß)	Sig.
Mydriasis	Hues[a]							
	Red	0.84	0.36	5.35	1	2.32	1.14–4.71	.02
	Yellow	0.86	0.32	7.14	1	2.36	1.26–4.44	.01
	Green	0.66	0.29	5.28	1	1.93	1.11–3.42	.02
	Cyan	0.16	0.26	0.40	1	1.17	0.71–1.95	.53
	Blue	–0.22	0.26	0.73	1	0.80	0.49–1.32	.39
	Saturation	2.39	0.78	9.47	1	10.91	2.39–49.90	.002
	Lightness	–1.61	0.54	8.89	1	0.20	0.07–1.73	.003
Miosis	Hues[a]							
	Red	0.95	0.36	7.06	1	2.56	1.28–5.21	.008
	Yellow	0.68	0.31	4.62	1	1.97	1.06–3.63	.03
	Green	0.54	0.28	3.65	1	1.72	0.99–2.97	.06
	Cyan	0.36	0.25	1.98	1	1.43	0.87–2.34	.16
	Blue	0.20	0.25	0.64	1	1.22	0.75–2.01	.42
	Saturation	–1.03	0.76	1.87	1	0.36	0.08–1.57	.17
	Lightness	–0.24	0.52	0.22	1	0.79	0.28–2.18	.64

Note. SE=standard error; df=degree of freedom; CI=confidence interval; OR=odds ratios; Sig=significant level at 0.05; [a]Reference is magenta

Namely, a 0.1 unit increase in the level of saturation was likely to be related to a 27% increase in the chance of coming under its higher category. Amongst the hues, compared to the count of magenta, significantly important predictors were yellow (OR = 2.36; 95%CI, 1.26 to 4.44; Wald $\chi^2(1) = 7.14$; p = .01), red (OR = 2.32; 95%CI, 1.14 to 4.71; Wald $\chi^2(1) = 5.35$; p = .02), and green (OR = 1.93; 95%CI, 1.11 to 3.42; Wald $\chi^2(1) = 5.28$; p = .02). In other word, the potential for the higher category of the amplitude of mydriasis was likely to increase by 2.36, 2.32, and 1.93 times in accordance with a one-unit increase in the count of yellow, red, and green. On the contrary, a significantly negative association between the amplitude of mydriasis and the level of lightness was found with OR = 0.20, 95%CI 0.07 to 1.73, Wald $\chi^2(1) = 8.89$, p = .003. This suggests that a 0.1 unit increase in the level of lightness was associated with a 15% decrease in a probability to belong to a higher category of mydriasis amplitude.

Second, the counts of both red and yellow were significantly positively associated with the amplitude of miosis (OR = 2.56, 95%CI = 1.28 to 5.21, Wald $\chi^2(1) = 7.06$, p = .008; OR = 1.97, 95%CI = 1.06 to 3.63, Wald $\chi^2(1) = 4.62$, p = .03; respectively), although the other chrominance components did not have significant associations with it.

This study has attempted to investigate whether the patterns of pupillary responses during watching a video are related to its chrominance components. While the chrominance components were less likely to be associated with the frequency of miosis, some considerable predictors of the rest of the pupillary responsive patterns were found. The level of lightness was negatively involved in both frequency and amplitude of mydriasis. On the other hand, positive relationships with both frequency and amplitude of mydriasis were found in the level of saturation. While any significant relationships between the frequency of both pupillary responses and the count of hues were not present, the amplitude of both responses had three important hues: red, yellow, and green. Both counts of red and yellow commonly had a positive association with the amplitude of both responses, and that of green were significantly involved in a positive relation with the amplitude of mydriasis only.

Many previous studies have asserted that pupillary responses can be affected by colors with evidence which the photoreceptors playing a major role in transducing the absorbed light into neural signals function differently in the visible spectrum. Under scotopic and mesopic conditions, color perception is still available in spite of biased perception towards gray, blue, or green which are dominated by rods,[25] and the human pupil is more sensitively constricted by the short-wavelengths of visible light.[26-28] Further, intrinsically photosensitive retinal ganglion cells (ipRGCs) are able to induce slowly sustained miosis and especially, an intense exposure to short-wavelength light accentuates this response.[26-29] On the other hand, under photopic condition, coordinated activation of the three types of cones results in trichromacy,[30,31] and the corresponding pupillary response is transient miosis in accordance with increase in color luminance rather than color itself.[26-28] Since our study was done under the condition with 200 lx ambient illumination and 300nit display luminance, both rods and ipRGCs were less likely to be involved in the results of this study. Accordingly, this study needed to focus on pupillary responses under photopic condition.

Amongst hues, this study revealed that red, yellow, and green are significantly associated with the pupillary responses. Unlike other vertebrates, primates utilize aggregate neural signals from L- and M-cones to perceive luminance,[32] so that the three hues within medium- and long-wavelengths are expected to perform an important role in luminance perception. As reported in a recent literature,[28] larger long-wavelength stimuli are able to increase in the amplitude of miosis in some degree. This finding suggests that both red and yellow in this study are likely to have a proportional relation with the amplitude of miosis, and the outcomes of this study confirmed it. Interestingly, however, the three hues also had a positive association with the amplitude of mydriasis as well as that of miosis. As shown in Fig. 2, these hues had relatively lower levels of both saturation and lightness than magenta as a reference color for the analysis. Consequently, it is inferred that hue itself have more relevant to miosis than to mydriasis.

Considering the Helmholtz-Kohlrausch effect which colors under isoluminance condition tend to be perceived brighter as the level of saturation increases,[33] it is inferred that the level of saturation is closed related to miosis. However, this study demonstrated that a positive relationship with the level of saturation was preferable to the frequency and amplitude of mydriasis rather than those of miosis. A recent study utilizing skin conductance response (SCR) examining a form of sympathetic reactions such as mydriasis showed that higher levels of saturation had a corresponding increase in attention regardless of hues.[34] Further, Alnæs *et al*.[35] reported that increasing attention accompanied less than 0.5 mm mydriasis as well as activation in the related sites of the brain such as locus coeruleus, frontal eye field and superior parietal lobule. Taken together, the reason why mydriasis is related to the level of saturation is thought to correlate considerably with both cognitive attention and corresponding physiological reaction.

Lightness as an achromatic component in HSL color space expresses the brightness of colors, and the colors brighten up as the level of lightness increases.[36] Now that increasing the average level of lightness in this study has rising effect on background brightness, it is possible that miosis is more likely to be induced than mydriasis. Interestingly, however, this study showed that the level of lightness is negatively associated with both frequency and amplitude mydriasis rather than those of miosis. While these findings appear that an indirect influence of the level of lightness upon mydriasis far outweighs its direct influence upon miosis, there is no enough evidence to support this assumption so that further investigation is required.

The auditory effects on the pupillary responses in this study is less likely to be considerable. Although unexpected or loud auditory stimuli have an effect to increase the pupil diameter,[37,38] such an orienting pupillary reflex might be restrictively affected in this study due to the synchronization between audio and video streams with a lower level of volume. Moreover, the pupillary orienting reflex induced by auditory stimuli does not show continuous patterns.[39] While some repeated patterns exist, they tend to become habituated.[40] On the other hand, if audio was not provided individuals might easily feel bored and fatigued, resulting in an effect to decrease the pupil diameter.[41] The provision of audio elements is therefore less likely to be biased on the basis of the outcomes of pupillary responses in this study.

The most important limitation of this study was that the average measurement of each pixel per frame of the video calculated by the video analyzer was used as main colors. The average measurement is less reasonable to represent the single color information of the video consisted of various colors in each frame. In the previous studies,[11-19] static base monochromic stimulus was utilized and figure out that only constriction was responsive to such color stimulus. Meanwhile, this study revealed that both constriction and dilation were still responsive to dynamic multicolor, and that their frequency and amplitude were more responsive to hues far away from the base colors. It namely suggests that the pupillary responses are more closely related to the other colormetric parameters such as saturation and lightness than hue itself. To specify this finding, a further study is needed to measure the color data in accordance with each fixation point.

CONCLUSIONS

The present study provides the first reported data on utilizing a longer length of video under natural viewing conditions and on analyzing the functional association between chrominance components and the patterns of pupillary responses. In addition to the physiological pupillary response to the light, the outcomes of this study suggest that the perception of color system in real visual environment is also functionally involved in the pupillary responses. Particularly, the chrominance components are more closely related to mydriasis than to miosis. While green color is considerably related to the amplitude of mydriasis, the most important factor for mydriasis is saturation amongst the chrominance components. These findings signify that a visual stimulus with highly saturated green color can be useful to any future studies for investigating any effects of colors on mydriasis. Moreover, highly saturated green color is considerable for any clinical examination requiring mydriasis. Finally, studies with different levels of display luminance are needed to further reconfirm the findings from this study in order to evaluate how much the association between the chrominance components and the pupillary responses is physiologically independent from display luminance.

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일반 시청 조건에서의 색상 성분과 동공 반응

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목적: 본 연구는 일반 시청 조건하에서 색상 성분과 동공 반응과의 기능적 관계를 알아보고자 시행되었다. **방법:** 정상 시력을 가진 12명의 피험자들의 동공 데이터는 45분간 뮤직비디오를 시청하는 동안에 아이트래커를 통해 수집되었고, 이 데이터는 색상, 채도 및 명도와 같은 색상 성분들과 함께 분석하였다. **결과:** 동공 분석 결과 산동과 축동은 반응 횟수와 반응량이 유사하였다. 색상들의 총 노출 횟수는 동공 반응량과 정적 상관관계를 보였고, 이러한 관계는 6가지 대표 색상들 중에서 빨강과 노랑에서 보편적 특징으로 나타났다. 축동 횟수와 축동량은 채도와 명도 수준과 유의한 관계를 보이지는 않았지만, 산동 횟수와 산동량은 채도와는 정적 상관관계를 가졌고 명도와는 부적 상관관계를 보였다. **결론:** 색상 성분들은 기능적으로 축동 보다는 산동과 더 밀접한 관계가 있는 것으로 사료된다.

주요어: 동공, 산동, 축동, 색상, 채도, 명도