Experimental Eye Research 151 (2016) 212–221

Contents lists available at ScienceDirect

Experimental Eye Research

journal homepage: www.elsevier.com/locate/yexer

Research article

The effects of light sources with different spectral structures on ocular axial length in rainbow trout (*Oncorhynchus mykiss*)

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ARTICLE INFO

Article history:
Received 25 January 2016
Received in revised form
18 August 2016
Accepted in revised form 29 August 2016
Available online 2 September 2016

Keywords:
Ocular elongation
Myopia
Monochromatic lighting
Wavelength
Blue light
Chromatic defocus
Axial length
Indoors lighting

ABSTRACT

Every day, we are acquiring more and more clues regarding the effects of different spectral structures (SS) of light on ocular axial length (OAL). As a step towards understanding this association, this study sought to characterise the effects of light sources of different SS on OAL in fish through comparisons with indoor daylight. The experimental design was completely randomised with 4 treatments and 2 replications. Three hundred and fifty two rainbow trout (*Oncorhynchus mykiss*) were housed in 8 tanks and fed for 71 days. Differences in the mean values of ocular elongation were determined at the end of the experiment. The daylight group was exposed to indoor daylight in the hatchery environment, the red group was exposed to long wavelength light (600–650 nm), the green group was exposed to mid-wavelength light (495–570 nm) and the blue group was exposed to short wavelength light (420–495 nm). The values of the OALs in fish grown under the same light intensity, but with light of different spectral characteristics, demonstrated significant differences ($p < 0.05$). The mean OAL in the daylight group was determined as 3.64 ± 0.40 mm, as 3.70 ± 0.35 mm in the red group, as 3.53 ± 0.34 mm in the green group and as 3.42 ± 0.29 mm in the blue group. The mean OAL in the blue group was significantly shorter compared to the red ($p = 0.003$) and the daylight groups ($p = 0.02$). When compared with the long wavelength light and indoor daylight, the effect of short wavelength light on OAL in fish was observed to be negative. Exposure to light with modified SS of in indoor environments may be effective in stopping ocular elongation.

1. Introduction

Today, myopia is a significant public health issue. Especially in Southeast Asia, its prevalence is increasing rapidly in many countries (Goh and Lam, 1994; Matsumura and Hirai, 1999; Wu et al., 2001; He et al., 2004; Lin et al., 2004; Logan et al., 2005; Jobke et al., 2008; Morgan et al., 2012). In some regions, up to 90% of children are myopic and 20% of these children have developed degenerative myopia that poses an increased risk for chorioretinal disorders (Jung et al., 2012).

With the steady increase in the prevalence of myopia, investigators continue the search for etiological factors other than family history. In particular, the effects of strong environmental factors have been suggested for the increase in myopia in children of school age all over the world. The most up-to-date studies suggest an association of myopia progression with either reading or the presence or absence of natural daylight (Saw et al., 2002; Norton et al., 2006; McKnight et al., 2014). The current prevailing point of view on controlling the problem is to increase the length of time and direct exposure to daylight (Rose et al., 2008; McKnight et al., 2014; Guo et al., 2013; Lin et al., 2014; Read et al., 2014; Jin et al., 2015). In retrospective studies, a negative relationship has been found between the duration of time spent outdoors and myopia progression (Guo et al., 2013). However, hypotheses explaining the relationship between the duration of time spent outdoors and myopia progression are not easy to prove, because the outdoor environment is significantly different from the indoor environment. The most important differences between the indoor and

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http://dx.doi.org/10.1016/j.exer.2016.08.018
0014-4835/

outdoor environments are the intensity of light and the spectral composition of the light. While the indoor light intensity is described in figures of hundreds, outdoor light intensities can reach tens of thousands of lux. Furthermore, the spectral composition of outdoor light comprises large quantities of ultraviolet (UV) and infrared (IR) rays, in addition to light in the visible spectrum. However, the short wavelength and the UV portion of the spectrum are largely absent indoors; if artificial lighting is used, the composition of the light is usually inclined towards the red end of the spectrum (Liberman, 1991; Bugner et al., 2006; Phillips et al., 2012). The changes in the spectral composition of the light and the diurnal and seasonal changes in the intensity of light continuously render the indoor and outdoor environments different from each other. Furthermore, many factors, such as the pupil size, homogeneous outdoor dioptric environment, the decreased need for accommodation or an increase in physical activity playing a role in myopia progression, cannot be controlled in experimental models in humans.

The refractive status of an eye is a complex variable, determined by the balance of the optical power of the cornea and the lens, and the ocular axial length (OAL) (Stenstrom, 1948; Benjamin et al., 1957; GWHM van Alphen, 1961; Larsen, 1971). Myopia occurs when the OAL grows beyond the combined optical power of the cornea and the lens. The correlation with myopic refractive error is larger for axial length than for any other component (0.76) (GWHM van Alphen, 1961). The correlation between the change in OAL and progression of myopia is between 0.77 and 0.89, which is high (Fulk et al., 2000; Gwiazda et al., 2003). Compared to other ocular components, OAL is typically regarded as the primary determinant of myopic refractive error. It is widely accepted that age-related myopic shift is mainly attributable to excessive axial elongation (Millodot, 1981; Charman and Jennings, 1982; Mutti et al., 2000; Seidemann et al., 2002; Atchison et al., 2004; Logan et al., 2004). Control of the axial elongation of the eye during development is thus crucial in preventing myopia.

Every day, we are acquiring more and more clues regarding the effects of different spectral structures (SS) of light on OAL. Due to the SS of light, differences have been determined in the OAL of subjects in experiments performed on animal species. While ocular elongation is observed in experimental animals grown under red light with long wavelength in SS, ocular elongation has been observed to stop under the dominant short wavelength of blue light (Kröger and Wagner, 1996; Long et al., 2009; Liu et al., 2011; Wang et al., 2011). However, in these models, comparisons with models grown under daylight have not been made. Furthermore, the effect of spectral composition of the lights and the luminance has not been adequately addressed. Similarly, the difference in the SS of daylight in residential areas, which can be partially explained by examination of the filtering effect of the windows in addition to the light reflecting indoors (Quill et al., 2004), can possess a critical role in the OAL in living beings. Starting from this point, we foresaw that the changes we made in the SS of indoor artificial lighting systems would be as effective as natural daylight in the prevention of ocular elongation. In the fish model that we created to test this hypothesis, we compared the effects of light sources demonstrating different SS and indoor daylight with similar intensity, controlled in the mechanism, on OAL.

2. Methods

2.1. Animal housing

Permission for the study was obtained from the Experimental Animals Local Ethics Committee. All fish were cared for according to the Guidelines of the Yuzuncu Yil University Experimental Animals Local Ethics Committee directives and the ARVO Declaration for the Use of Animals in Ophthalmological and Vision Research. This study was performed at the Van Yuzuncu Yil University Research and Application Farm Hatchery.

The rainbow trout (*Oncorhynchus mykiss*), which was chosen as the fish type for the study, was obtained from a private fish trading company (Miss Fish farm, Gurpinar, Van, Turkey). Rainbow trout with mean weights of 4.39 g were integrated into the study environment with the equipped vehicle belonging to the company, and adaptations were begun. The water used in the study was passed through a sand filter (STF Faber) prior to addition to the fish tanks. Two airstones were used for each tank. The backwashing of the sand filter was performed twice a day, every morning and evening. Air ventilation of the tanks used in the study was provided with the help of the blower of 750 W capacity (Resun GF 750). The water change in the tanks was on a continuous basis, and the water discharge was arranged as 5.5 lt/min equally in all groups. The water quality parameters: temperature, dissolved oxygen and pH were monitored on a twice-daily basis, in the morning and the evening. The cleansing of the tanks was performed on a regular daily basis. The trout fish bait (Skretting, Turkey) was used in the study, and bait of 1.6 mm was used in the adaptation stage. The experimental stage was begun with the 2.0 mm bait. Later, according to the growth of the fish, the size of the bait was increased to 3.0 mm and later on, a 4.0 mm bait was used. The bait feeding was performed with the hands and ad libitum, twice a day. (Supplementary Material 1).

2.2. Experimental design

There were a total of 352 rainbow trout (*Oncorhynchus mykiss*) with average weights of 9.80 ± 0.84 g at the start of the experiment. Rainbow trout were placed in the experimental tanks after having undergone fish-grading, and measurements of their weights, lengths and OALs (Table 1). A scoop with an aperture size of 1.5 mm was used for to obtain samples of the fish. In order to equally distribute the fish, a wooden growth housing of accordion type with aluminium grill bars (Akuamaks, 40 × 40 × 20 cm) was used. The tops of the tanks were covered with monofilament fish net to prevent the fish from jumping out of the tanks. For the 8 cylindrical polyvinyl chloride tanks of 500-L volume capacity, 90 cm diameter and 50 cm height, 4 separate boxes with separated waterproof parts were prepared in the laboratory setting. The specially designed growth tanks were mutually independent.

A completely randomised design was established with 4 treatments and 2 replications, making a total of 8 plots. After 25 days of acclimatisation, 352 fish fed with commercial feed were selected and distributed randomly in 8 500 L aquaria. The stock density in each group was 88 fish/m3. The experimental unit consisted of 44 fish. The groups were tagged and named according to the colour characteristics of the light in the environment: daylight, red, green or blue. Differences in the mean values of ocular elongation were found at the end of the experiment. The ocular elongations were measured using ultrasonographic biometry.

2.3. Lighting design

The aquaria exposed to daylight were positioned inside the room where they would receive a light intensity of approximately 50 lux during the day at the surface of the tank. In order to ensure this, throughout an adaptation period of 25 days, we collected lighting intensity measurements every hour over the surfaces of the aquaria from 7 a.m. through 5 p.m., and the tanks that would be exposed to daylight were placed in specific locations in the room