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The retinular responses of common squid *Todarodes pacificus* for energy efficient fishing lamp using LED

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ABSTRACT

Blue light has outstanding transmission characteristics in the sea, and is known to cause the most sensitive visual response in common squid *Todarodes pacificus*. Application of a light emitting diode (LED) that can efficiently emit monochromatic light is expected to bring enormous energy savings. LED can produce cost-effective low-wattage irradiance at the specific wavelength. This study investigated the retinular responses of common squid *T. pacificus* to colored LED lights and light adaptation conditions based on the Perkinje effect, which is the tendency for the luminance sensitivity of the human eye to shift depending on the bright and dark adaptation states. The changes of the retinular response to blue, red and white LED were investigated in the bright and dark adaptation conditions in the water tank experiment. The degree of light adaptation was similar between the bright adaptation state and dark adaptation state to blue light, which suggests that squid retina is highly sensitive to blue light as it has been reported to date. On the other hand, the degree of light adaptation to red LED light showed a tendency to increase, albeit slightly, over time. However, the degree of light adaptation to white light with wide wavelength band showed similar tendencies as to the case of red light in the dark adaptation condition, and was actually superior to the case of blue light in the bright adaptation condition. Also, the degree of light adaptation of the retina cells collected from the sea experiment was found to be between the range of 20 and 40%. From these results, blue light may be regarded as an excellent luring source as the retina of squid is highly sensitive to it, but it cannot be determined as the most ideal LED color for the purpose of catching fish.

1. Introduction

The fishing lamp is a key component of the boats luring and catching squid, which is considered as one of the important fishery resources. Along with the developments in society, the latest light sources were used as a fishing lamp from torch, acetylene, incandescent, mercury, fluorescent and halogen lamps to the current metal halide lamps [1,2]. Squid jigging, which is one of the most common areas where fishing lamps are used, saw development with increased illuminating power of fish-luring lights that allowed more deep fishing but brought on the problem of excessive consumption of fuel compared to the catch. The increase of illuminating power heightened the cost of equipment related to fish-luring lights and fuel, causing a financial burden in the fishing industry. In order to relieve the excess spending, researches on the light utilization technology considering the behavioral characteristics of squid in response to light were performed [3,4]. Also, researches on the behavioral characteristics of squid in response to light inside labs or to fishing lamp or the moonlight in the sea were conducted [5,6].

Light emitting diode (LED) is garnering attention as the light source of the future. LED is considered as an eco-friendly light source as it has low power consumption, contains no mercury and has a long life. LED was reviewed as a potential fishing lamp based on its illuminating characteristics and the prospects for its development as a fishing lamp were reported [7,8]. Using blue LED, we can reduce maximum more than 90% of energy consumption, arising from the high transmitting characteristic of blue LED. In addition, the behavioral response of Japanese common squid to the colored LED light in a lab [9] and the performance of luring fish using LED light in the sea were investigated [9–12]. However, these studies did not clarify the fishing procedures of squid jigging nor

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did they sufficiently consider the criteria for light sources to be considered as an appropriate fishing lamp. In order to solve these problems, a physiological approach is needed to identify the degree of light adaptation of the eyes to colored LED lights.

In this study, we've focused on building a database about the light adaptation of the common squids through water tank experiment and field test in order to make a decision which LED light source is more effective on fishing and catching the squids. This research attempted to identify the appropriate light color for fishing LED light by investigating the retinular responses of common squid *Todarodes pacificus* to LED colors (red, blue and white) in the bright and dark conditions and analyzing the degree of light adaptation of retina cells collected in the sea.

2. Materials and methods

2.1. Water tank and light source

The experiment tank was rectangular in shape (80*W* × 560*L* × 100*H* cm^3) and the water depth was maintained at 70 cm (Fig. 1). In order to ensure that the squids remain alive, a running water system that maintains the water quality at the optimum level was installed. Three types of colored light sources were used as shown in Fig. 1 and Fig. 2 shows the spectral distribution of blue, red and white. The maximum wavelengths of the blue and red LED light were 460 nm and 630 nm, respectively, and the wavelength width was 60 nm, whereas the white LED has wide wavelength band between 400 nm and 700 nm. The LED light source box (80*W* × 80*L* × 20*H* cm^3) was installed 30 cm above the water surface to ensure even penetration downward. The water temperature was maintained at 10.2 °C (9.8–10.7 °C) and salinity at 35.2‰ (35.0–35.3‰). The brightness of the light was measured using an illuminometer (Minolta, T-10WL) immediately beneath the light source at 50 cm below the water surface. Common squids *T. pacificus* with an average length of 23.9 cm (20.5–27.7 cm) were used in the experiment.

2.2. Brightness conditions and adaptation

The illumination level that squids are normally active in the sea was designated as a dark adaptation condition (0.05 lx) and the maximum brightness of each of the colored LED lights used in the experiment was designated as a brightness adaptation condition (red: 8.75 lx, blue: 11.42 lx, white: 34.5 lx). In order to ensure that all the squids in the experiment received the same light stimulation, a rectangular cage (58*W* × 60*L* × 75*H* cm^3) was made. The order of the experiment procedures is as follows. First, the cage was

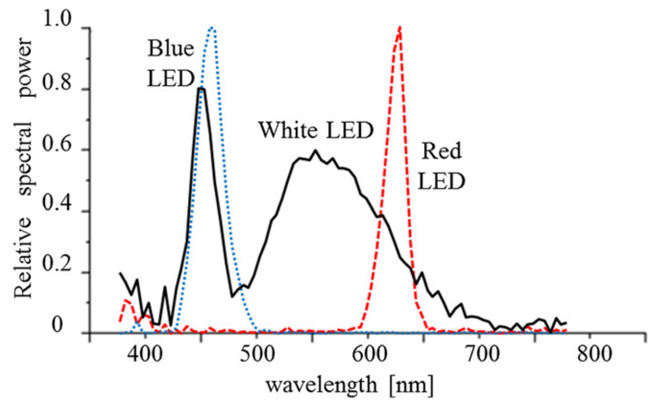

Fig. 2. Spectral distributions of the light sources.

placed underneath the LED light source box and 3 squids were placed inside. Second, the adaptation was allowed for approximately 90 min, and both eyes of the squids were collected at 10 min, 30 min and 60 min time lapse after each conditioned light stimulus. Then, each specimen was fixated in Bouin's solution and embedded in paraffin after dehydration. After, tissue samples were created in cross sections of 4∼6 μm in thickness, and were stained with a HE (hematoxylin eosin) for comparison and observation under microscope. The degree of light adaptation of retina was represented as a percentage ($(b/a) \times 100$) with *a*, representing the thickness between the basement membrane and the surface of retina, and *b*, representing the migration of black pigment. Fig. 3 shows the migration of black pigment in the retina when it was stimulated by light.

2.3. Field test in the sea

We also investigated the retinular response of common squids *T. pacificus*, which were caught by boats using fishing LED light in the southeastern sea of Korea in February 2011. Fig. 4 shows the experiment location in the sea. The average length of the squids used in the experiment was 23.4, and the water depth, from which the squids were hauled, was 107–135 m. Both eyes were collected from 30 common squids that were caught between 4 p.m. and 4 a.m. the following day, and the degree of light adaptation of retina was investigated. In order to observe the time lapse dependent changes in the light adaptation of retina, the retinas of common squids collected at each time lapse were collected. Each of the specimens was fixated on the boat and washing, embedding,

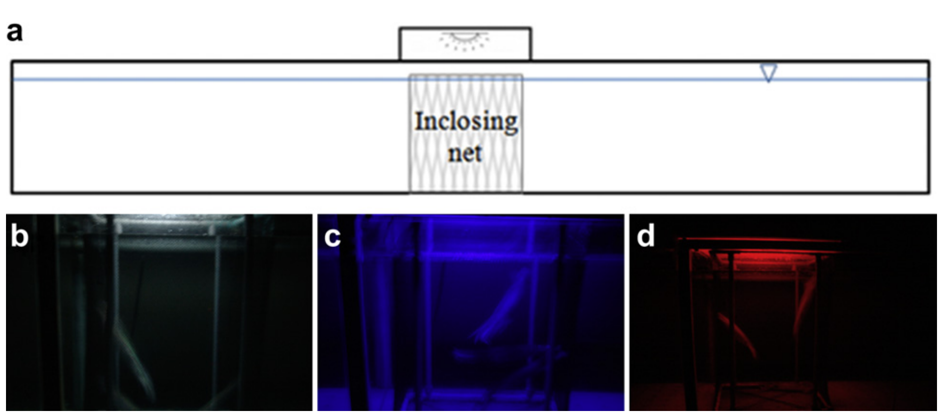

Fig. 1. Set-up of experiment tank: (a) the position of light source; photograph of water tank with the light source of (b) white LED, (c) blue LED, and (d) red LED. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)