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THE RESPONSE TO ROTATING OBJECTS BY *ANOTOGASTER SIEBOLDII* (SELYS) MALES, Pt 2 (ANISOPTERA: CORDULEGASTRIDAE)

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It has been reported that the response to rotating objects by *A. sieboldii* ♂♂ indicates recognition of the objects as ♀♀. The influences of colour, size and rotation velocity (RV) of discs on hovering ratio (HVR) were studied with experiments using a small electric rotating device. Among the rotating discs with white, yellow, orange, red, green, or blue alternating with black, the one with green elicited the highest HVR (98%), whereas the HVR to the yellow/black disc was lowest (32%). This suggests that yellow has a role as a warning coloration against predators rather than being involved in intraspecific recognition. – In the relationship of the HVR to RV of the green/black disc, the HVR reached a peak around 20-25 Hz. In relation of HVR to the size of the disc, the larger the diameter of the disc, the higher was the HVR, and when different sizes of discs were put side by side, *A. sieboldii* ♂♂ had a tendency to respond to the larger disc of the pair.

INTRODUCTION

ARAI (1986) and ISHIZAWA & ARAI (2003) reported that males of *Anotogaster sieboldii* (Selys) responded to rotating objects by hovering to face the objects, and they regarded this behaviour as an attempt to approach a conspecific female by sexually motivated males that had recognized such rotating objects as females. The result of the previous experiments (ISHIZAWA & ARAI, 2003), however, involved deficiencies as follows: the colour patterns were not systematically arranged and the rotation velocity was over estimated with a tachometer due to the influence of diffusion reflection. The authors noted in their report that these deficiencies should be addressed in the future. Hence experiments were conducted in which the relationships of hovering ratio (HVR) of *A. sieboldii* males to colour patterns, rotation velocity, size of discs, and whether they prefer a larger disc to a smaller one or vice versa could be revealed.

STUDY SITE, MATERIAL AND METHODS

Experiments were executed from mid August to early September 2002 and in late August 2003 and 2004, at the same site as that in a previous report (ISHIZAWA & ARAI, 2003), a small stream adjacent to a bog on a campus of Waseda University (Fig. 1). This site is located in a valley of the Sayama Hills, Mikajima-horinouchi, Tokorozawa City, Saitama Prefecture. About four or five hours a day were allotted to the experiments.

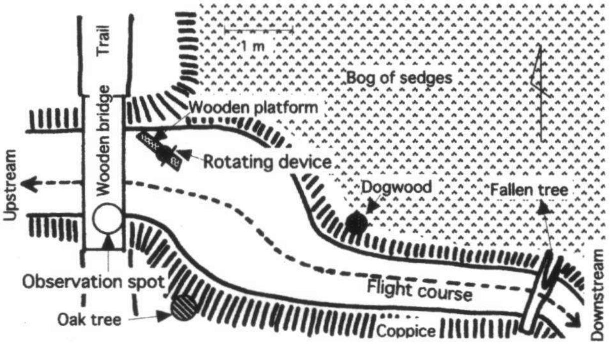

Fig. 1. Plan view of the study site (modified from ISHIZAWA & ARAI, 2003.)

A small electric fan (Senju Co., Mini Desk Fan EF-001) was used as in the experiments in 2001 (ISHIZAWA & ARAI, 2003). Several kinds of discs mentioned below were fixed at their centres to the shaft of the mini fan instead of propeller blades. In order to measure the rotation velocity (RV) of the discs, a non-contact tachometer (CUSTOM, RM-2000; measuring range: 30.0-30,000 rpm, sampling time: 1.0-2.0 s) was used.

Discs of various sizes were cut out of a sheet of cardboard (1.0 mm thick and 6 or 9 cm diameter) and out of a sheet of polyvinyl chloride board (0.4 mm thick and 12, 15 or 18 cm diameter). Paper label-sheets on which the colour patterns shown in Figure 2a were printed with an ink-jet printer were pasted on six discs of 12 cm diameter, while only the green and black pattern (GB) was pasted on the other sizes of disc. The reverse of each disc was painted mat black and two silver marks were spotted on its edge, opposite to each other, for measuring precisely the rotational velocity of the disc.

The rotation velocity of discs was controlled by changing the voltage. This was varied from 1.5 to 7.5 V by changing the kind of batteries (AM1 to AM3) and the number of them connected. Thereby the rotation velocity (RV) could be changed from around 10 to 110 Hz.

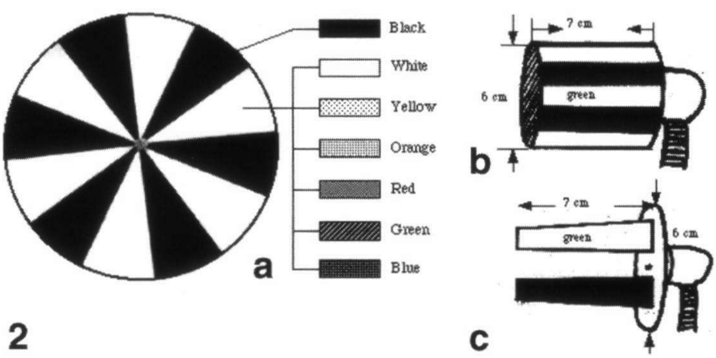

Fig. 2. Equipment used: (a) the basic pattern of the discs used in the experiments; the colour combinations were: white and black (WB), yellow and black (YB), orange and black (OB), red and black (RB), green and black (GB), blue and black (BlB); – (b) rotational cylinder with green and black stripes; – (c) the two-blade rotational device.

The rotational objects were set facing downstream as in the report of ISHIZAWA & ARAI (2003), and the frequency of dragonflies that visited the experiment site flying upstream was counted as visiting frequency (VF), along with some that came from upstream and turned back to face the discs.

Hovering for 2.0 seconds and over or circulating flight around the device after hovering for less than 2.0 seconds was defined as hovering (HF). The hovering ratio (HVR) is defined as the hovering frequency divided by the visiting frequency: HF/VF. In experiment 4, when a male responded more than once and alternatively to each disc at one visit, every hovering episode was counted separately.

Experiment 1. – The hovering ratio (HVR) to discs of 12 cm diameter (Fig. 2a) was investigated. The rotation velocity (RV) of each disc was around 24 Hz. Six different colour patterns were used (Fig. 2a). The order of setting of the discs was at random and the disc was changed at an interval of around 25 VF.

Experiment 2. – The relationship of the rotation velocity (RV) to the hovering ratio (HVR) was investigated by using the green/black (GB) pattern since this was the one that caused the highest HVR in *A. sieboldii* males. RV ranged from 10 to 110 Hz.

Experiment 3. – The relationship of the hovering ratio (HVR) to the size of GB discs was investigated. The size of the discs were 6, 9, 12, 15 and 18 cm in diameter, and the RV was around 24 Hz.

Experiment 4. – Whether males of *A. sieboldii* discriminate the difference in the size of two green/black (GB) discs set side by side and separated from each other by 60 cm was determined, together with any size preference shown.

Experiment 5. – Hovering frequency (HVR) to a cylindrical (Fig. 2b) or two-blade rotational device (Fig. 2c) was investigated.

Each disc (or cylinder or blade) in Experiments 1 to 3 and 5 was tested for at least VF = 50. In Experiment 4 each set was tested for VF = 15 , except for the combination of the 9 cm and 12 cm discs, which was tested for VF = 60. The position of each set was changed over at VF = 15. A Chi-square test was used to compare the HVRs.

The body size was measured of *A. sieboldii*, which were collected in 1990, 2001 and 2002 at the same site where the experiments were conducted.

RESULTS

RESPONSE TO COLOUR PATTERNS (Exp. 1)

Figure 3 shows the hovering ratio (HVR) elicited by each disc colour pattern described in Fig. 2a. Of the colour patterns, the green/black (GB) combination gave the highest, 98% HVR; this was followed by WB (56%), BlB and OB (44% each), RB (40%) and (the lowest) YB (32%). The difference of HVR between GB and that elicited by the other discs was significant ($p<0.001$); among the other discs the differences were not significant ($p<0.2$).

RELATIONSHIP OF HVR TO THE ROTATION VELOCITY OF DISCS (Exp. 2)

Figure 4 shows the HVR of *A. sieboldii* males to various RV of the GB disc. The HVR was at its highest when the disc was rotating in the region of 20-25 Hz. There is some indication that the HVR decreased below a RV of 20 Hz. At frequencies above 30 Hz it declined, reaching zero in the 70 to 100 Hz range. However, the data at higher frequencies were scanty. There were no data below a RV of 10 Hz because the voltage under 1.5 V could not be regulated.

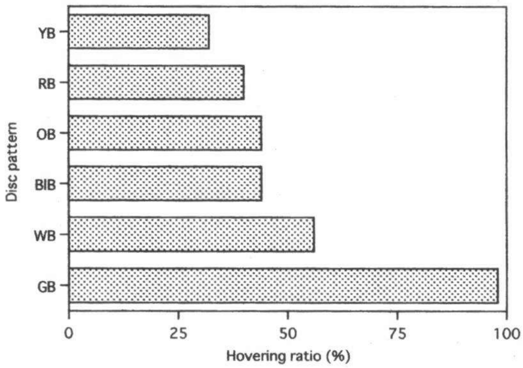

Fig. 3. The hovering ratio (HVR) of *Anotogaster sieboldii* males to each disc colour pattern. Each disc was 12 cm in diameter and the rotation velocity (RV) was around 24Hz for each pattern. The colour combinations were as follows: white and black (WB), yellow and black (YB), orange and black (OB), red and black (RB), green and black (GB), blue and black (BlB).

RELATIONSHIP OF HVR TO DISC SIZE (Exp. 3)

Figure 5 shows the relation of HVR to various sizes of GB disc rotating at around 24 Hz. The HVR elicited by the 6 cm diameter disc was as low as 36%, but it increased with increase in disc size: 81% for 9 cm, 85% for 12 cm, 97% for 15 cm and 99% for 18 cm. However, it should be noted that the RV of the 12 cm disc was only 19 Hz, i.e. slower than the RV of the other discs. The HVR was significantly different between the 6 cm disc and the 9 cm disc ($P<0.01$). However, in spite of the apparent increase in attractiveness to *A. sieboldii* males as disc diameter increased, the HVR was not significantly different among the discs larger than 6 cm ($P<0.5$).

PREFERENCE OF DISC SIZE (Exp. 4)

Table I shows the hovering ratio (HVR) by *A. sieboldii* males to the different sized discs when two discs were set side by side. In any combination of disc sizes, males responded more to a larger disc than to a smaller one, though there was no significant difference in each matching due to the scantiness of the data. Nevertheless, overall, the HVR to the larger disc size group was significantly greater than that to the smaller disc size group ($p<0.02$).

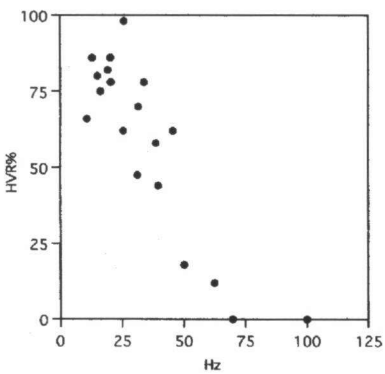

Fig. 4. Relationship of the hovering ratio (HVR) to the disc rotation velocity (RV) in the experiment using a green and black patterned (GB) disc of 12 cm diameter.

RESPONSE TO THE OTHER ROTATING OBJECTS (Exp. 5)

The HVR to the rotating cylinder (25.2 Hz) was 88%, while that to the rotating two-blade propeller (15.5 Hz) was 58%. These are comparable values to those achieved by the 12 cm diameter disc.

Table I
Hovering ratio (HVR) of *Anotogaster sieboldii* males to the different sizes of GB disc set side by side

Matching disc size (cm)	Visiting frequency (VF)	Hovering ratio (HVR:%) smaller disc	lager disc	p
6:9	30	16.7	40	P< 0.1
9:12	60	45	66.7	P< 0.2
12:15	30	36.7	70	P< 0.1
15:18	30	60	86.7	P< 0.3
Total	*150*	*40.7*	*66*	*P<0.02*

On August 22 2003, in the process of these experiments, a curious scene was observed of a response to reflection of sunlight by a male of *A. sieboldii*. The male hovered for a while to flickering of the sunlight reflection from sprays associated with a low water fall into the stream in the afternoon.

DISCUSSION

It was previously indicated that *A. sieboldii* males show a strong response to green rotating objects over those of other colours (ISHIZAWA & ARAI, 2003), and the result of the current experiments confirmed this. It may well be associated with the fact that both sexes of *A. sieboldii* have large emerald green compound eyes at the anterior end of a black body (with yellow stripes). Photoreceptors in the ventral compound eyes of dragonflies respond to ultra-violet (340-410 nm), green (490-540 nm) and orange red (620 nm) in *Sympetrum rubicundulum* (MEINERZHAGEN et al., 1983), or to ultra-violet (356 nm) and green (520 nm) in *Aeshna cyanea* (EGUCHI, 1971). The traits of the photoreceptors of *A. sieboldii* may be similar to those of *A. cyanea*, because the former species shows a strong response to green. As *A. sieboldii* showed weak association to yellow, this colour might have a role of warning coloration against its predators rather than that of intraspecific recognition. *A. sieboldii* males showed a rather high HVR to a white and black disc, though the reason for this is not obvious. As ISHIZAWA & ARAI (2003) suggested, the movement and silhouette of the colour pattern with white and black might have been recognized more

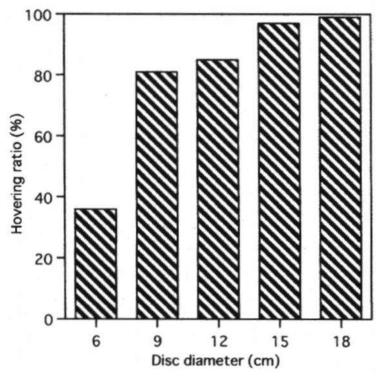

Fig. 5. Relationship of the hovering ratio (HVR) to the disc diameter, using a green and black (GB) patterned disc. The RV of each disc was around 24 Hz except for the 12 cm diameter disc, which had a RV of about 19 Hz.

clearly than those of other colour combination with black (i.e. yellow, orange, red and blue - but not green). The above mentioned phenomenon might also be an outcome of the common trait that caused attraction of *A. sieboldii* males to the movement of a white and black pattern, which is similar to that of the reflective wingstroke of conspecific females.

As to the relationship of HVR to RV, ISHIZAWA & ARAI (2003) noted that males responded to rotating objects at a rotation velocity from 120 to 500 Hz. However, these values were measured erroneously due to low of precision of the tachometer. As Figure 4 shows, HVR was higher at a RV of 20-25 Hz than at other rotation velocities. Judging from the fact that *A. siebodii* males cannot distinguish between rotating objects and conspecific females (ISHIZAWA & ARAI, 2003), the RV of 20-25 Hz may be near to the wingstroke frequency of the female (or the male) in flight. The wingstroke frequency of patrolling *A. sieboldii* males was not examined. However, the wing stroke frequency during warming-up was 30-35 Hz (ISHIZAWA & ARAI, 2003). MAY (1995) noted that at high air temperatures *Anax junius* males reduce the wingstroke frequency for thermoregulation of the body temperature, and indeed the slow fluttering of the wings of *A. sieboldii* males at high air temperatures could clearly be seen. Accordingly, *A. sieboldii* males may be flying at low wingstroke frequencies, and the high HVR at 20-25 Hz seems to be related to this.

The decrease in HVR above a RV of 50 Hz is close to the upper limit of wingstroke frequency of *A. sieboldii.* Thus the maximum wingstroke frequency elicited by a strong stimulus - pinching on the thorax - was 49 Hz in a male and 48 Hz in a female, respectively (ISHIZAWA & ARAI, 2003). Although it was not possible to test HVR at less than 10 Hz in the current study, judging from ARAI's observation (in ISHIZAWA & ARAI, 2003) that the males of *A. sieboldii* did not respond to an electric fan at 11 Hz, it is likely that below 10 Hz HVR is much lowered.

The fact that *A. sieboldii* males showed higher HVR to larger size discs is consistent with the conclusion of ISHIZAWA & ARAI (2003) that this species has a propensity to show higher HVR to the larger diameter of discs. TINBERGEN (1958) noted that in Europe males of the butterfly, *Hipparchia semele* (Satyridae), were strongly attracted by objects with a size twice (4 times in area) as large as that of its own body at the distance of one meter, although at a shorter distance of 50 cm the larger one attracted less. Also the same thing was noted by MAGNUS (1958), who concluded that males of a fritillary butterfly, *Argynnis paphia*, reacted to dummies of which size was as large as possible. As *A. sieboldii* males responded to the rotating fan of the outdoor unit of an air conditioner, the diameter of which was around 40 cm (ARAI, 1986), they may respond to large rotating objects that are more than three times as large as their own wings (span of forewing: 12 cm). At the apron of the local airport for small airplanes at Amimachi, Ibaraki pref., an officer of the airport observed and informed me that dragonfly carcasses (species unknown) were often found. The dragonflies might have been attracted to, and hit by, propeller blades, the normal rotation velocity of which during idling was 10 Hz.

The female *Hipparchia semele* is larger than the male, and TINBERGEN (1958) indicated the propensity of a male that tended to be attracted by larger females. *A. sieboldii* females have a larger thorax than males, being exceptional among the Anisoptera, and a longer abdomen; thorax: 14.2±0.5 mm, n = 4, 13.5±0.7 mm, n = 46; abdomen: 80.8±1.2 mm, 74.0±2.0 mm, in the female and in the male, respectively. Like the grayling, females of *A. sieboldii* are quite large, so males of *A. sieboldii* may have similar behavioural traits to males of the grayling.

Since *A. sieboldii* males could not recognize even females unless the latter were in the action of fluttering (ISHIZAWA & ARAI, 2003) and they responded to a rotating cylinder etc., and to the spray of a short waterfall, it is suspected that *A. sieboldii* males have poor visual capacity, notably resolving power. TINBERGEN (1958) noted that *Hipparchia* males responded to anything that moved fluttering or circling around; therefore he concluded that the butterfly had poor vision.

This propensity of responding to rotational objects has been found not only in *A. sieboldii*, but also in males *Tanypteryx pryeri*, *Oligoaeschna pryeri*, *Orthetrum j. japonicum*, *O. triangulare melania* and *Caloptelyx cornelia* (N. Ishizawa, unpublished). Also it has been found in orange-winged males of *Mnais pruinosa costalis* (Dr Y. Tsubaki, pers. comm.), and in males *Matrona basilaris japonica* and *Boyeria maclachlani* (KANO, 2003). Accordingly, it is suspected that there may be many other dragonfly species that respond to rotational objects and, if so, it would be interesting to ascertain whether or not the males have the same kind of recognition of females as in *A. sieboldii*. Also, some of them may be territorial, and further investigation of the relationship of such a characteristic behaviour to their territoriality would be rewarding.

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