Postural control under clinorotation in upside-down catfish, *Synodontis nigriventris*

Ken Ohnishi¹, Akihisa Takahashi², Masato Koyama³ and Takeo Ohnishi²

¹Department of Physiology, and ²Department of Biology, Nara Medical University, Kashihara, Nara 634, Japan
³Senior Research Engineer Frontiers Joint Research Program Department, Japan Space Utilization Promotion Center, Nishiwaseda, Shinjuku-ku, Tokyo 169, Japan

**Abstract** The upside-down catfish *Synodontis nigriventris* has a unique habit of swimming and resting upside-down in free water. This behavior leads to the assumption that the catfish has a specific gravity information processing system. We examined the postural control behaviors in the catfish under clinorotation which is usually used for producing pseudo-microgravity. *Synodontis nigriventris* kept its body posture at a stable area of the rotated flask in which the catfish was kept, when it was clinorotated at the rate of 60 rpm. In contrast to *Synodontis nigriventris*, a related species, *Corydoras paleatus*, did not show such steady postural control. When the flask was rotated at a lower rate of 30 rpm or a higher rate of 100 rpm, *Synodontis nigriventris* as well as *Corydoras paleatus* showed a considerable disturbed control of body posture. In this condition, they were frequently rotated with the flask. These findings suggest that *Synodontis nigriventris* has a high ability to keep upside-down posture and the gravity sensation in this catfish is likely to contribute to its different postural control from that of many other fishes.

**Key words**: upside-down catfish, clinostat, microgravity, postural control

**Introduction**

Almost all fishes keep their posture with the ventral side towards the water bottom under normal conditions. This postural control in fishes depends on the dorsal light response (DLR) and gravitational response (von Holst, 1935; von Baumgarten et al., 1975). If illuminated from an upper side, fishes tend to orient their dorsal side towards the illumination due to DLR. Since the body tilt is also controlled by the gravitational response, fishes can not tilt their bodies over a certain angle and consequently never take an upside-down posture. However, when the vestibular apparatus is dissected, fishes can orient their dorsal side straight towards a light source even if the illumination is from the lateral side (von Holst, 1950). In this case, the postural control mainly depends on visual inputs. In contrast to such postural control observed in many other fishes, the upside-down catfish shows a unique postural control behavior (Meyer et al., 1976b; Nagaishi et al., 1989; Ohnishi et al., 1996). The catfish swims and rests upside-down even when a light source is above it. When the catfish is close to objects, it orients its ventral side towards objects: it swims upside-up along the water bottom like other fishes. This behavior is the so-called ventral substrate response (VSR) which is also observed in some other fishes (Meyer et al., 1976a).

The upside-down swimming observed in upside-down catfish seems to be controlled by gravity differently than other fishes. At present, it is unknown how the vestibular apparatus contributes to the unique postural control. To examine the contribution of gravity sensation to this postural control behavior, we analyzed the postural control of upside-down catfish using a clinostat.

---

Received December 12, 1996
Accepted December 24, 1996
Address for correspondence: Takeo Ohnishi, Ph.D., Department of Biology, Nara Medical University, Kashihara, Nara 634, Japan Fax: +81-7442-5-3345
Materials and methods

Animals

Upside-down catfish (*Synodontis nigriventris*) and a related catfish (*Corydoras paleatus*) of 3-4 cm in body length, which were obtained from a local dealer (Kashihara, Nara, Japan), were used in the present study. They were maintained in aquariums at the water temperature of 23-25°C.

Clinorotation

A clinostat (KSU-96-L040, Kawasaki, LTD., Kakamigahara, Gifu, Japan) was used to expose the fish to clinorotation. As shown in Fig. 1, the clinostat (370 mm in width, 375 mm in depth, 335 mm in height) has 6 rotatable round stages on vertical and horizontal planes. The horizontal plane is also equipped with 3 fixed round stages. The catfish were kept in cell culture flasks (25 mm²) filled up with water, and the flasks were fixed on the stages. The flasks were rotated at the rate of 30, 60 or 100 rotations per minute (rpm).

Analysis of postural control under clinorotation

The postures of the catfish under clinorotation at various rotation rates (30, 60 or 100 rpm) were recorded with a 8 mm video camera (UCV1Hi, Canon, Tokyo, Japan). Clockwise rotation was used in most experiments. Every 2 sec, the eye position was plotted as a dot on recording transparent sheets covering the monitor screen on the basis of replay pictures for 2 min. When the eye position was obscure, the mid-point between both eyes was plotted as an eye position. The plotted dots were divided by vertical and horizontal axes into four quadrants, and the percentages of occupancy of the dots in a quadrant were calculated from the number of plotted points. In some cases, the plotted eye positions were statistically analyzed with Van Valen-test (Van Valen, 1978) between the plotted dots in *Synodontis nigriventris* and *Corydoras paleatus*.

Results

Several posture types under clinorotation

*Synodontis nigriventris* showed several swimming postures under clinorotation. At the rate of 60 rpm, three typical types of posture (Fig. 2a-c) were observed during most periods of the rotation. The three types of posture could be
divided by the difference in the eye position occupying the upper-right (Fig. 2 a), upper-left (Fig. 2b) or mid-left area of the rotated space (Fig. 2c). In all types, Synodontis nigriventris kept the upside-down posture with its head slightly up, and the head was directed towards the anti-rotation direction. The posture was not affected by the change in intensity of room illumination. Even under a dark illumination (about 10 lux), the catfish kept these types of posture. At the rates of 30 and 100 rpm, passive rolling postures were frequently observed (Fig. 2d).

Comparison of posture under clinorotation between Synodontis nigriventris and Corydoras paleatus

The swimming posture under clinorotation at 60 rpm was compared between Synodontis nigriventris and Corydoras paleatus. Figure 3 shows the dots plotted as eye position of the catfish and occupancy rates of the dots in each quadrant as histograms. The eye positions of Synodontis nigriventris were not as widely spread compared with those of Corydoras paleatus. The statistical analysis showed a significant difference in the eye positions between Synodontis nigriventris and Corydoras paleatus (VanValen-test, $t_{118} = -5.36$, $p<4.16 \times 10^{-7}$). Corydoras paleatus also showed disturbed swimming postures at 30 and 100 rpm similar to that at 60 rpm.

Individual differences in swimming postures observed at different rotation speed

The swimming postures under clinorotation at 30, 60 or 100 rpm were examined in 5 Synodontis nigriventris, and the typical examples obtained from 3 fish are shown in Figure 4. The effect of the change in clinorotation rates on the eye position was observed in all tested fish. The eye position at 60 rpm was stable compared with that at 30 and 100 rpm, but clear individual differences were observed in the eye positions at 60 rpm. At 30 and 100 rpm, Synodontis nigriventris showed marked disturbed eye position except for fish #3. The frequency of upside-down posture at these rates decreased, and passive body rotations depending on flusk rotations were frequently observed. Fish #3 showed a stable eye position at 30 rpm.

Direction of clinorotation and swimming posture

The relationship between the direction of clinorotation and swimming posture was analyzed at the rate of 60 rpm in two fish (Fig. 

---

**Fig. 3** Comparison of the eye positions under the clinorotation at 60 rpm between Synodontis nigriventris (a) and Corydoras paleatus (b). Occupancy rates were obtained from the dots plotted as eye positions shown in histograms. I, II, III and IV represent the first, second, third and fourth quadrant, respectively. The numbers represent the distance (mm) from the rotation center(0).
5). With the change from clockwise direction to anti-clockwise direction, the eye position of fish #1 changed from the upper-right area (Fig. 5a) to the upper-left area (Fig. 5b) of the rotated space. Contraversal phenomenon was observed in fish #2 (Figs. 5c and d). The eye position changed from the upper-left area to the upper-right area in accordance with the change in the rotation direction. There was a clear rotation direction-dependency in the swimming posture under clinorotation.

Posture under horizontal rotation

To check the effect of the centrifugal force produced by the rotation on postural control, posture under horizontal rotation was analyzed.

Synodontis nigriventris and Corydoras paleatus kept upside-up postures around the center of the rotated flask (data not shown).

Discussion

We found that the upside-down catfish, Synodontis nigriventris, can keep a stable eye position under clinorotation compared with a related catfish, Corydoras paleatus (Fig. 3). This finding suggests that the upside-down catfish has a relatively high ability to keep its posture undisturbed even under disturbed fluid flow. However, the reason of such difference in postural control between two species is presently unclear. Possibly, the ability to take an upside-

Fig. 4  Eye positions under clinorotation at various rotation rates in three upside-down catfish.

a, d and g, 30 rpm; b, e and h, 60 rpm; c, f and i, 100 rpm.  a, b and c, fish #1; d, e and f, fish #2; g, h and i, fish #3.
down posture gives the catfish high postural control ability.

This postural control ability in upside-down catfish depended on the rate of rotation (Fig. 4). All the fish tested here showed high ability in swimming postural control at 60 rpm. In addition to, at this rotation rate, the area where the stable eye position was maintained was very different among the fish (Fig. 4b, e and h). It seems that there was no specific position in keeping the stable swimming posture. When we applied a higher rate of clinorotation (100 rpm), we found no ability in swimming postural control and no individual differences among the tested catfish. These may be due to the strong fluid forces produced by the rapid rotation.

Another individual difference in the postural control ability under clinorotation was clearly observed at 30 rpm. Particularly, fish #3 showed a high ability to maintain a stable eye position at this rate (Fig. 4g). The ability in swimming postural control in the upside-down catfish may not be uniform among individuals. We assume fish #3 was sensitive to low fluid forces produced at 30 rpm compared with the others, fish #1 and fish #2. In addition, the eye position under clinorotation depended on the direction of rotation (Fig. 5). The mirror image-like change in the area where the stable swimming posture was kept suggests that such area is very stable in individuals. This direction-dependency of swimming postural control is thought to be due to the direction of the fluid flow.

In the case of horizontal rotation, the upside-down posture was not observed. Due to VSR, the distance between the catfish and the bottom of the flask was too short to analyze the effect of rotation because of VSR.

Clinostats are generally used for producing pseudo-microgravity to examine its effect on the

![Fig. 5](image-url) The effect of the direction of clinorotation on the eye position under clinorotation at 60 rpm in two upside-down catfish. a and c, clockwise rotation; b and d, anti-clockwise rotation. a and b, fish #1; c and d, fish #2.
growth of culture cells fixed on T-flasks. However, in the present study, since the upside-down catfish was in water, the fish was considered not to be exposed to pseudo-microgravity. Fluid forces seem more effective on the postural control than pseudo-microgravity. In deed, the eye position under clinorotation changed according to the change in the rate of rotation or the direction of rotation. Thus, the present findings obtained from clinorotation are thought to be based mainly on the effect of fluid forces. From this reason, the direct effect of pseudo-microgravity on the postural control in the upside-down catfish was not estimated. However it is certain that the upside-down catfish has a high ability to keep its posture under a disturbed fluid flow. This ability may depend on the vertical rather than the horizontal directional fluid flow.

These findings strongly support the hypothesis that *Synodontis nigriventris* has a specific postural control mechanism different from other fishes. Two possible explanations for this mechanism can be proposed. One explanation is based on a control system at the peripheral level. The input patterns from the vestibular apparatus to the central nervous system (CNS) may be constant regardless of the change in the body posture. Meyer et al. (1976b) has reported that the configuration of the otolith organs in *Synodontis nigriventris* are very similar to those of normal swimming catfish (*Silurus glanis* and *Malapterurus electricus*). However, the arrangement of sensory cells in the otolith organ and the direction of sensory hairs of the cells are not yet examined; thus, the abnormality at the cellular level may cause the specific control mechanism of upside-down posture. Another explanation is based on CNS. The outputs of CNS to motor units may be fixed regardless of gravitational inputs from the vestibular apparatus. The on-off switching between upside-down and upside-up postures may be not affected by the sensory feedback from the vestibular apparatus but other sensory organs. Only when the catfish is close to objects, the upside-down posture may be inhibited by VSR-related sensory inputs. Without VSR-related sensory inputs, the catfish may switch on a channel to orient its ventral side towards the up side. This hypothesis is supported by the observation that mid-postures between upside-down and upside-up were not kept during swimming or resting in free water.

Visual inputs seem not to contribute to the postural control in the catfish because the swimming patterns under clinorotation were not affected when the catfish was confronted with dark illumination. Ijiri (1995) observed in the Second International Microgravity Laboratory (IML-2) that a type of *Oryzias latipes*, which have a high ability to maintain normal posture under microgravity conditions, showed a disturbed posture under dark illumination. The postural control of this strain is likely dependent on visual rather than gravitational inputs. In addition, Takabayashi et al. (1987) reported that the goldfish *Carassius auratus* showed a disturbed swimming posture, looping response, under microgravity. The postural control mechanism under disturbed gravitational condition may be different between *Synodontis nigriventris* and *Oryzias latipes* or *Carassius auratus*.

The present study has shown that the upside-down catfish has a relatively high ability to keep its posture undisturbed even under clinorotation. Thus, exposing this catfish to microgravity is very useful for studying the postural control mechanism. Space experiments using this fish will be required in the future.

**Acknowledgement**

This study is carried out as a part of “Space Utilization Frontiers Joint Research Projects” promoted by NASA and Japan Space Utilization Promotion Center.

**References**

Ijiri, K. 1995. Fish mating experiment in space—what it aimed at and how it was prepared. Biol. Sci. Space, 9: 3-16


