Relationship between frequency of upside-down posture and space size around upside-down catfish, *Synodontis nigriventris*

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Abstract The catfish *Synodontis nigriventris* shows a unique habit taking a stable upside-down posture in free water regardless of an above, one-sided illumination. This upside-down posture can be observed when the catfish is apart from objects because the catfish usually orients its ventral side towards the water bottom or objects due to a so-called ventral substrate response. Thus, it is not easy to study the mechanism of the upside-down posture. To resolve this problem, the frequency of the upside-down posture was measured by using various sizes of vessel in which the catfish was kept. Video analysis showed that the frequency of the upside-down posture depended on the space size around the catfish. The smaller the size became, the higher the frequency of the upside-down posture became. Furthermore, the frequency of the upside-down posture depended on the shape of the vessel bottom. Curved-bottom vessels induced the upside-down posture more frequently than flat bottom. These findings suggest that a small, curved-bottom vessel is ideal for researching the upside-down postural control mechanism.

Key words: upside-down catfish, upside-down posture, shape recognition, postural control

Introduction

The unique postural control of upside-down catfish *Synodontis nigriventris* was first reported by Meyer et al. (1976b). The catfish swims and rests upside-down in free water. However, the upside-down posture is not always observed. When the catfish is close to objects, it tends to orient its ventral side towards objects. This response is the ventral substrate response (VSR), which has been demonstrated in other fishes as well by Meyer et al. (1976a). Thus, like other fishes the catfish usually swims upside-up near the water bottom. This upside-up swimming is predominantly observed to upside-down swimming, unless the catfish is apart from objects.

The upside-down posture in the catfish seems not to be controlled by the dorsal light response or gravitational response system generally observed in many other fishes. This uniqueness provides a good opportunity for studying the postural control mechanism under a different gravity condition. However, the infrequency of the upside-down posture makes it difficult to further analyze the upside-down postural control mechanism. If experimental conditions which can induce more frequent upside-down postures are determined, the effects of visual or gravitational information on the upside-down posture can be analyzed with more ease. The present study was aimed to find experimental conditions that induce more frequent upside-down posture.

Materials and methods

Animals

Upside-down catfish (*Synodontis nigriventris*) of 3-4 cm in body length were obtained from a local dealer (Aqua family, Kashihara, Nara, Japan). They were maintained in aquariums at the water
temperature of 23-25°C. All experiments were performed under the same temperature.

Analysis of behavior patterns

Typical upside-down posture was photographed with a 35 mm camera (OM-2N, Olympus, Tokyo, Japan). Since the catfish usually swam very rapidly, it was very difficult to photograph the upside-down posture. To solve this problem, the swimming path in the aquarium was observed: the catfish tended to take a preferred swimming path. Thereafter, photographs were taken at one point of the swimming path, where the swimming speed became slower.

To examine the relation between the space size around the catfish and the frequency of upside-down posture, the behaviors in various sizes of beakers, 100 ml (55 x 70 mm), 200 ml (67 x 89 mm), 300 ml (78 x 103 mm), 500 ml (90 x 120 mm) and 1000 ml (110 x 150 mm), or medium bottles, 100 ml (55 x 129 mm), 200 ml (66 x 148 mm) and 500 ml (88 x 192 mm), were recorded with a 8 mm video camera (UCV1Hi, Canon, Tokyo, Japan) under natural daylight conditions. Each beaker or bottle was filled with water up to its labeled maximum scale. The recording process of the behaviors was as follows. The first serial recordings were performed in the order of large beaker or bottle to small, and then the next serial recordings were small to large. At one size, two recordings were performed. The first recording was performed for 5 min simultaneously after the translocation of the catfish into the beaker or bottle. The second recording was performed for 5 min after resting for 10 min. The catfish was kept in the beaker or bottle for 20 total min. The medium bottle containing the catfish was laid for the 20 min. The period of upside-down posture was measured from replay pictures of the two recordings. The frequency of upside-down posture was obtained from the mean of two measurements.

Results

Behavior patterns

The catfish usually rested at the water bottom upside-up or vertically on the aquarium walls, orienting its ventral side towards the plane. When the catfish was apart from the bottom or the vertical plane over about 3 cm, it usually showed upside-down swimming or less frequently, upside-down resting posture. Typical upside-down posture of the catfish is shown Fig. 1. In most cases, the upside-down swimming speed was more rapid compared with that of upside-up swimming. The upside-up swimming was frequently accompanied with prey searching on the water bottom. When the catfish was close to the water bottom (horizontal plane) within about 3 cm, it oriented its ventral side towards the water bottom, rolling the body (Substrate response-H). Take-off behavior from the water bottom with body rolling was induced when it was apart about 3 cm from the water bottom. When the catfish was close to the vertical plane within about 3 cm, it oriented its ventral side towards the vertical.

Fig. 2 Behavior patterns of upside-down catfish.
plane with or without body rolling (Substrate response-V). In this case, the substrate response with head-up posture was rarely observed. Translocation towards an upper or lower direction was frequently observed on the vertical plane. The translocation towards an upper direction frequently induced take-off behavior towards the water surface. These behavior patterns are shown in Fig. 2.

Frequency of upside-down posture

The effects of space size around the catfish on the frequency of upside-up posture were examined using various sizes of beakers or medium bottles. Figure 3a is representative data showing clear beaker size-dependent frequency of upside-down posture. In the recording order of large beaker to small, upside-down posture were rarely observed in the 1000 ml beaker during the recorded period, but upside-down posture slightly increased in 500 and 300 ml beakers (about 5%). Marked increases in upside-down posture were observed in 200 (about 25%) and 100 ml beakers (about 38%). In the recording order of small beaker to large, the frequency of upside-down posture decreased with the increase in beaker size. The change in the frequency of upside-down posture was more clear in the first serial recordings than in the second serial recordings.

In contrast to the clear beaker size-dependent frequency change of upside-down posture, the size-dependency was not as clear in bottles, as representatively shown in Fig. 3b. However, the upside-down posture frequency was relatively high in bottles. Even in the 500 ml bottle, about a 45% frequency of upside-down posture was observed. In each serial recording, the highest frequency of upside-down posture was observed in the 100 ml bottle.

Discussion

The present study has shown that the frequency of upside-down swimming in Synodontis nigriventris is affected by the space size around the catfish. This size-dependency of the upside-down swimming seems to result from the quantitative change in VSR against the vertical plane. With the decrease of space size, the catfish is given more chances to approach the vertical plane, and consequently, VSR against the vertical plane increases. Since the catfish tends to take off from the vertical plane towards the water surface with an upside-down posture, it is thought that the size-dependency of upside-down swimming is due to the take-off response from the vertical plane. Most upside-down postures were observed after the take-off response.

Fig. 3 Frequency of upside-down posture in beakers (a) or medium bottles (b) in upside-down catfish showing representative results.
Furthermore, it has been shown that the frequency of upside-down swimming is also affected by the shape of the vessel in which the catfish is kept. The frequency of upside-down posture in the bottle was relatively higher than that in the beaker (Fig. 3). Even the highest rate in 100 ml beaker was similar to the rate in the 500 ml bottle. Since the bottles were laid during experiments, it seems that a curved shape rather than a flat shape of the water bottom more frequently induces upside-down posture. The higher frequent upside-down posture observed in the bottles may be not due to a simple cause of different bottom size between the bottles and the beakers, because larger bottom size in the bottles than in the beakers did not result in lower frequency of upside-down posture. The catfish probably has a high ability to recognize the bottom shape of vessel correctly. We examined the effects of the barbels or eyes on upside-down posture by removing them. However, no significant effects were observed after these surgical operations. Thus, other type sensory information rather than touching or visual information plays an important role in recognizing object shape. Lateral-line organs or sensory cells distributed over the body surface may contribute.

The biological function of the upside-down postural control is still unclear. Meyer et al. (1976) presumed that the upside-down posture contributes to catching prey at the water surface. The dark color of the ventral side seems to play a role in such feeding behavior at the water surface by camouflaging the body. However, since many other fishes which catch prey at the water surface usually take the upside-up posture, it is questionable that the upside-down posture indeed contributes to the feeding behavior. Alternatively, the upside-down swimming may result from the development of VSR against the vertical plane. That is, frequent take-off behaviors from the vertical plane might give more chances to produce the upside-down swimming. Upside-down posture seems to be more suitable for the take-off behavior from the vertical plane towards the water surface than upside-up posture because body rolling is not required for upside-down take-off: from our observation, the catfish frequently rests on the vertical plane with head-up posture.

Another interesting issue is why the upside-down swimming is observed in this species: Nikol'skii (1961) reported the similar swimming pattern in a very close species, Synodontis victoriae. According to Chardon (1968), Siluriformes have three suborders, Siluroidei, Bagroidei and Loricarioidei. Synodontis nigriventris and Corydoras paleatus belong to Bagroidei and Loricarioidei, respectively. From the phylogenetical tree, Synodontis nigriventris is regarded as a higher-evolved species than Corydoras paleatus. Thus, the upside-down swimming seems to be obtained in a later evolutionary step. However, other species belonging to Bagroidei have not acquired this unique habit. Judging from these evidences, the unique postural control may result from the mutation of postural control-related genes. If so, Synodontis nigriventris has some morphological deficiencies in the peripheral or central nervous system which controls body posture. This assumption is very contrast to the above described assumption that the unique habit results from the behavioral development.

From the present findings, experimental conditions which induce upside-down posture more frequently were proposed. The size and shape of vessel in which the catfish was kept was very effective for the induction of upside-down posture. In tested vessels, 100 ml volume of medium bottle was the most effective. This type of vessel is ideal for the analysis of upside-down posture change in response to gravitational stimulation.

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