Regulation of movement in pigeons by electrical stimulation of FRM brain region

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Abstract

Robo-pigeon is a special robot that controls the behavior of a live pigeon by applying electrical stimulation to its brain nerve or muscle tissue. The Frontal Region of the Mesopallium (FRM) is the commonly used stimulus region for robot pigeons at present, and the electric stimulation FRM region is mainly used for the steering control of pigeons. This study devised an experimental paradigm aimed at stimulating the FRM brain region to induce spatial cognition and facilitate memory formation in pigeons. During the experiment, pigeons were placed inside a specifically marked circle, and whenever the pigeon tried to leave the circle, its FRM brain region was electrically stimulated. Experiments have shown that pigeons can form a solid spatial memory of the marked area after about a week, and a small amount of stimulation can cause pigeons to move within a certain area. This study introduces a novel control function for the robot pigeon achieved through electrical stimulation of the FRM brain region, thereby broadening the application scope of the robo-pigeon.

Keywords

robo-pigeon, animal robots, FRM brain region

1. Introduction

Animal robot is a new type of robot, which is different from traditional robots in both structure and principle. Animal robot is based on animals and stimulates its neural targets through electrical signals generated by electronic devices to achieve artificial regulation of animal movement behavior [1]. The concept of animal robot was proposed by Chapin et al in the early 21st century [2]. Compared with traditional bionic robots, animal robots have natural advantages in the aspects of smoothness, environmental adaptability and power supply ability.

Current research on animal robots covers many species, such as insects [3, 4, 5], rodents [6, 7], fish, birds [8] and so on. Among them, birds, especially pigeons, have attracted much attention

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from researchers because of their ability to move freely in three-dimensional space, sensitive response, strong continuous flight ability, good homing ability, excellent spatial navigation ability and memory properties. At present, most robot pigeons control the movement of pigeons by directly applying electrical stimulation to the brain nerves of experimental animals, and perform movement behaviors such as turning left, turning right, taking off [9] and going straight [10] according to the experimental expectations. This way of controlling behavior is achieved by direct electrical stimulation of the relevant brain regions, one of which is the Frontal Region of the Mesopallium (FRM) brain region.

The FRM is an important region in the brain of pigeons, located in the prefrontal part of the mesotemporal cortex. This region plays a key role in the regulation of cognition and behavior in pigeons. Studies have shown that FRM are involved in the navigation, memory and decision-making processes of pigeons in complex environments. Specifically, it plays a crucial role in controlling movement and postural regulation in birds because it is a group of neurons widely connected to the spinal cord and cerebral cortex, and it is these neurons that are responsible for the processing and integration of motor instructions and regulate the motor behavior of pigeons by controlling the output of descending motor pathways [11]. Therefore, the motor behavior induced by neural stimulation in the FRM brain region is closer to the animal's own will. At present, FRM brain regions are mostly used to regulate steering behavior in animals. In this paper, the control function of FRM brain region was further expanded by stimulating the FRM brain region of pigeons to form spatial memory of specific regions.

2. Materials and Methods

2.1. Experimental Animals

Four adult pigeons (Columba livia, two males and two females, 450-550 g) were selected for this experiment, and their numbers were 007, 044, 068, and 075. Each pigeon was kept in solitary confinement and fed only during the experiment, which was conducted at a fixed time each day. Before the experiment began, the pigeons had their wings clipped and lost their ability to fly. Approval for all experiments in this study was obtained from the Life Science Ethical Review Committee of Huanghuai University (no. 20231103003).

2.2. Experimental Design

Before the experiment, electrodes were surgically implanted into the FRM brain region. After the surgery, the pigeons recovered for seven days, and then the experiment was carried out.

The experiments in this study were all conducted in a 3×3×0.7 m unroofed frame, as shown in Figure 1b. An appropriate amount of pigeon food (mainly soybean) was evenly distributed in the experimental site, and pigeons could forage freely in the site. There was a 1.5m diameter circle in the center area of the site, and the circle was surrounded by 18mm wide electrical insulation tape.

The experiment was divided into three stages. In the first stage, two days of environmental adaptation were carried out, during which pigeons were put into the field to forage freely until they stopped foraging. This process was mainly to familiarize the pigeons with the environment

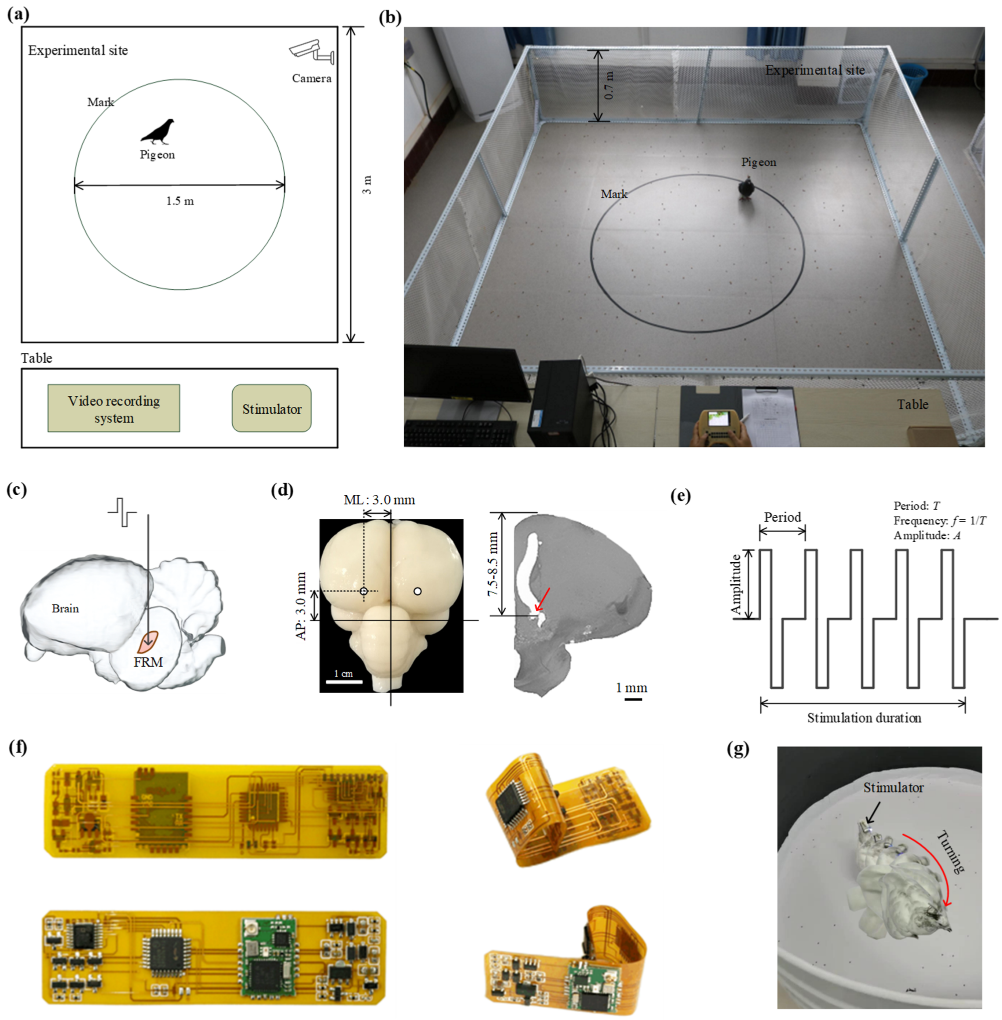

Figure 1: Experimental site and equipment. (a) Experimental site. The experiment was conducted in a 3×3×0.7 m unroofed field with a 1.5m diameter circle in the center of the field. The camera was set 3m above the center of the circle and recorded all the video information of the experiment. (b) Actual picture of the experimental site. The experimental site was set up for field shooting. (c) Electrode implantation location. The red area is the FRM brain region. (d) Specific coordinate location of FRM brain region. (e) Stimulation waveform. The period is defined as T; the frequency is defined as f = 1/T; the stimulation duration is defined as nT, n is an integer; The amplitude is defined as A. (f) Raw materials and production of neurostimulators. (g) The best effect of electrical stimulation of FRM brain region. The steering angle is between 120° and 180° for best results.

of the field, enable them to adapt to the subsequent experiment more quickly, and collect the movement tracks of pigeons without intervention. After the end of adaptation, the stage with the longest duration and the participation of electrical stimulation is carried out. The feeding range of pigeons is controlled in the central region. If there is a behavior of circling, the FRM brain region will be stimulated by electrical stimulation. In the third stage, the electric

Table 1
Optimal stimulation parameter

Pigeon ID	Amplitude (μA)	Stimulation duration (s)	Frequency (Hz)
007	0.74	0.25	100
044	0.65	0.74	100
068	0.75	0.35	100
075	0.82	0.50	100

stimulation was stopped, the pigeons were put into the experimental field to forage freely, and the movement of the pigeons was observed and recorded.

2.3. Surgery

Adult pigeons over 6 months of age (450-550 g, male and female) were first anesthetized with 3% pentobarbital sodium (0.12 mL/100g) into the chest muscle. After anesthesia, the head fur of the pigeons was shaved. A mixture of 2% lidocaine reagent and 5% epinephrine reagent was injected subcutaneously into the operating area for further local anesthesia. After the pain reflex disappeared, the pigeon's head was placed on a custom-made stereotaxic stand [12]. The midline of the scalp was incised, the residual connective tissue on the skull surface was scraped, and the location of the FRM region was determined based on the brain localization images of pigeons [13] (AP: 3.00mm, ML: 3.00mm, DP: 7.5-8.5mm) (Figure 1d). An insulated stainless steel electrode with A diameter of 25.4 μm was implanted and then fixed with dental cement. Finally, the neural interface is welded together with the electrode and sealed with dental cement around it. After sterilization, the wound was sutured with true silk thread, and the experimental test was performed 5 to 7 days after recovery.

2.4. Stimulators and Their Parameters

The neural stimulator (size 1.8×2.1×1.2 cm, weight 5 g) and wireless neural stimulation controller (Figure 1f) were designed by our team, including wireless communication module, control module, constant current source excitation module and battery. Through the wireless neural stimulation controller, the stimulation parameters of the neural stimulator can be controlled, and the parameters are transmitted to the wireless communication module of the stimulator through radio frequency. The control module enables the constant current source stimulation module to generate stimulus signals corresponding to the parameters received by the wireless communication module [14].

We need to find the stimulus parameters corresponding to each pigeon to achieve the best stimulus effect. The current intensity is 0.6 mA, the number of pulse train is 3, the duty cycle is 50%, and the frequency is 100 Hz (Figure 1e). The stimulation parameters are constantly adjusted, so that the steering Angle of pigeons is between 120° and 180° to achieve the best effect [13, 14]. Table 1 record the optimal stimulation parameters corresponding to each pigeon, and these parameters will be used for electrical stimulation of pigeons in the experiment.

3. Results

First of all, the first stage experiment was carried out. Pigeons were allowed to adapt in the experimental field for two days. The movement trajectory of the first day during the adaptation was shown in Figure 3a. In the process of adaptation, through the statistics of the movement distance of pigeons per minute, it was found that pigeons had the longest movement distance in the first ten minutes and showed a strong willingness to exercise. Therefore, in the follow-up experiment, we only counted the data of the first ten minutes.

After acclimating to the field, we took the next step of the experiment, restricting the movement of the pigeons to the designated area. Every time the pigeon tried to come out of the circle, we gave it an electrical stimulus. During the nine-day experiment, the trajectory of 007 during the first ten minutes of daily foraging is shown in Figure 2a. Over time, the pigeons became less and less willing to confront and try outside the circle and gradually gave in to foraging only inside the circle. Less and less electrical stimulation occurs with each experiment (Figure 2b). After nine days, the number of stimuli dropped to zero for three pigeons, and these three pigeons reached the maximum residence time in the area, and they were able to stay in the area for the entire duration of the experiment.

Next, we conducted the last stage of the experiment, cancelling the electrical stimulation in the previous stage and no longer interfering with the movement of pigeons, and observed the movement trajectory of pigeons at this time in Figure 3b, 3c. At this time, the pigeons mostly moved within the circle, in sharp contrast to the trajectory of the first stage.

In the experiments we observed individual differences between different pigeons. Over the course of the electrical stimulation experiment, some pigeons were more responsive to the electrical stimulation, showing faster adaptation and reduced attempts to step out of their enclosure. Other pigeons showed more resistance and probing behavior. Despite individual differences, all subjects formed stable spatial memory in a specific region, indicating that electrical stimulation has a certain universality and repeatability in spatial memory formation.

4. Discussion

This study successfully induced the formation of spatial memory of specific regions in pigeons by designing experiments and stimulating FRM brain region with electrical stimulation technology. The experimental results showed that after a certain period of intervention with electrical stimulation of FRM brain region, pigeons' residence time in the specific region increased significantly, and their behavior of exploring outside the circle gradually decreased, showing stable memory of the specific region. This finding not only provides new experimental evidence for the study of the formation mechanism of spatial memory in animals, but also explores the new function of FRM brain region in the movement regulation of robo-pigeon.

In this study, pigeons did not undergo any training in the first stage, when they had the largest foraging range and moved the farthest distance, and most tracks were distributed at the edge of the site, with little activity in the center (Figure 3a). The trajectory of this stage is in sharp contrast to that of subsequent stages, which is a strong evidence that pigeons have generated spatial memories of specific areas. The above experiments are sufficient to prove that

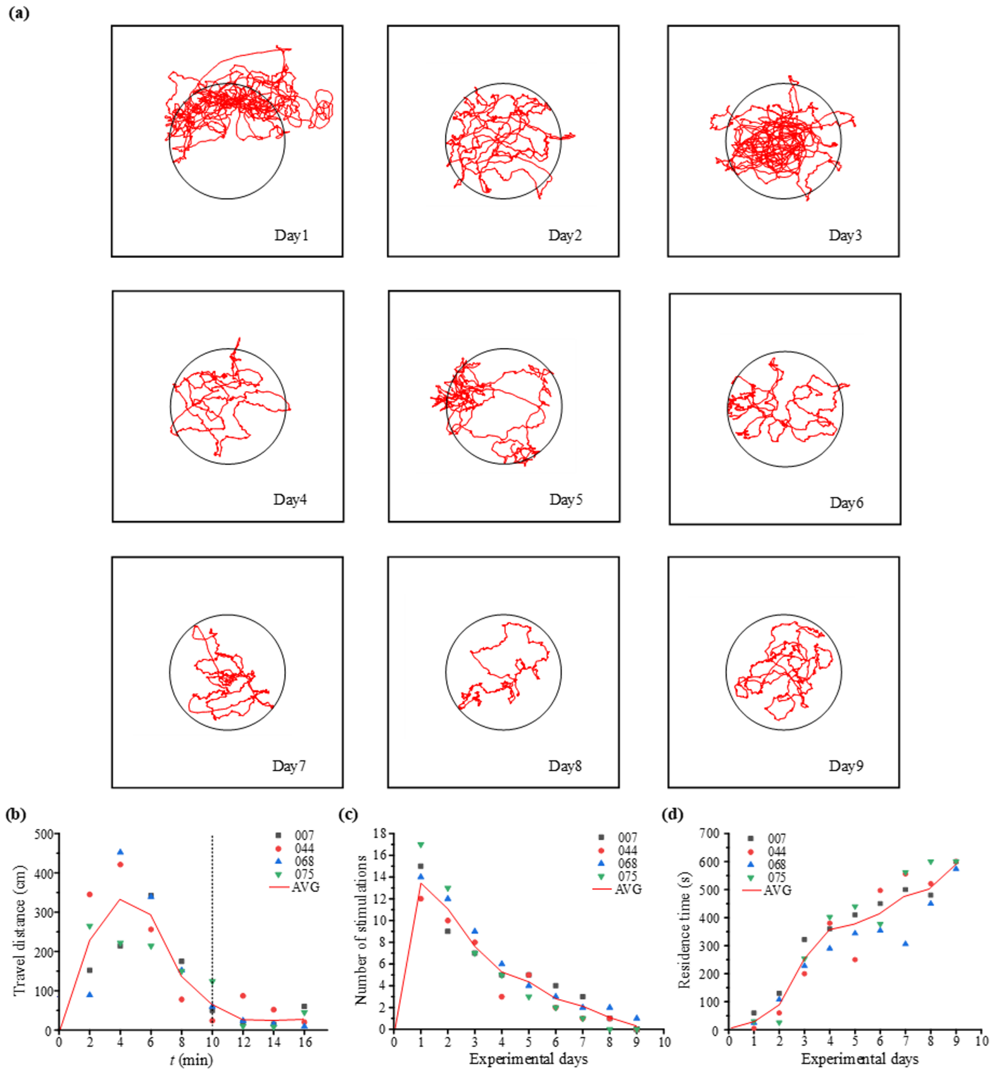

Figure 2: Track and data in memory formation. (a) Chart of trajectory changes during the training residency of 007. The trajectories in the figure were collected from the data ten minutes before the start of the experiment every day, when pigeons had a strong desire to forage and moved actively. (b) A statistical chart of the distance traveled by pigeons every two minutes during the first day of acclimation. (c) Daily stimulation statistics of four pigeons. (d) Statistics on the maximum daily residence time of four pigeons.

the FRM brain region can be electrically stimulated to make pigeons generate spatial memory for a specific region and stay in it for a long time, which expands the application scenario of animal robots in real life.

In this study, electrical stimulation was used as an intervention method, which has the advantages of simple operation and obvious effect. By fine-tuning the electrical stimulation parameters, we succeeded in controlling the pigeons' stay behavior in a specific area. However,

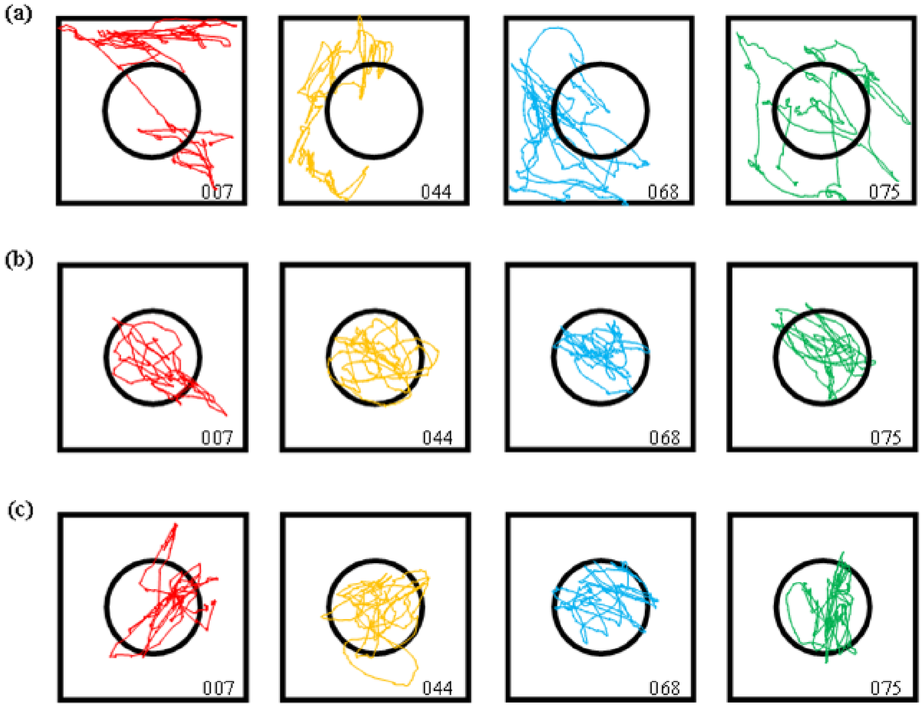

Figure 3: Comparison of the tracks of the first day of the adaptation period and the two days of the third stage. (a) The tracks of the four pigeons on the first day of the adaptation period. The trajectories in the figure were collected from the first ten minutes of the experiment each day, when pigeons had the strongest desire to forage and moved the farthest. (b) Movements of the four pigeons on the first day of the third phase. (c) Movements of the four pigeons on the second day of the third stage.

electrical stimulation technology also has some limitations, such as the stimulation effect may be affected by individual differences and environmental factors, which need to be further studied and optimized.

In this experiment, we observed that pigeons gradually showed a learned helplessness after experiencing multiple electrical stimuli, that is, giving up and reacting negatively to uncontrollable situations. This psychological phenomenon has been widely studied in the field of animal behavior and psychology [15, 16]. Learned helplessness may be related to the perception and control of the environment. Further exploration of the psychological mechanism of learned helplessness in pigeons will help us better understand the regulatory mechanism of animal behavior and mental state.

In addition to the FRM used in this study, there are many other control nuclei present in pigeons' brains that may play an important role in memory and cognition of specific regions of space, which can be electrically stimulated to regulate pigeons. For example, Substantia grisea et fibrosa periventricularis (SGP), one of the brain regions closely related to navigation and spatial cognition in birds, is involved in the formation of landmark navigation and path memory, and stimulation of SGP can produce fear. The Lateral Hypothalamus (LHy) is involved in learning and memory in birds, especially spatial memory and landmark learning, and stimulation of LHy can produce pleasant emotions. Therefore, in future studies, we can try to use these different control nuclei to regulate the behavior of pigeons, in order to further study the memory mechanism of pigeons in specific regional space. By manipulating these nuclei, it is possible to explore their influence on pigeons' spatial cognition and behavioral choices, as well as their functions and interactions in different contexts. This research contributes to a more comprehensive understanding of the neural mechanism of spatial memory in pigeons, and provides theoretical basis and practical guidance for designing more effective control methods and developing more intelligent robotic pigeon systems. At the same time, the study of other control nuclei in pigeon brain will also help to reveal the deeper neural basis of bird spatial cognition, and provide new research directions and ideas for the development of animal cognitive behavior and neuroscience.

5. Conclusion

In this paper, a new control method of robo-pigeon is developed through the study of pigeon movement regulation by electrical stimulation of FRM brain region, which solves the need of animal robot staying in a specific area for a long time in practical applications, such as disaster area search and rescue and natural environment monitoring by robo-pigeon. The formation process and representation of cognitive behavior of birds are analyzed, which provides a new research idea for the study of animal behavior. Looking forward, the integration of artificial intelligence (AI) with animal robotics holds tremendous potential. AI can enable more sophisticated and autonomous decision-making capabilities, allowing robo-pigeons and other animal robots to perform complex tasks with greater efficiency and adaptability [17, 18, 19]. We anticipate even more innovative applications and advancements in the field of animal robotics, driving progress in both scientific research and practical implementations.

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