Paper:

Linear Discrimination Analysis of Monkey Behavior in an Alternative Free Choice Task

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When we observe people, we can often comprehend their intention from their behaviors. The intentions expressed by individuals can be considered as existing in interpersonal space and from a current social context. In our daily activity, choosing socially correct behavior through the observation of such social context is essential. However, it is not known how we can decode intention from another's behavior. Here, we show how we can retrieve the intention of monkeys through external observation of their behavior patterns while performing alternative free choice tasks. We found that linear discriminant analysis on a monkey's motion parameters could provide a discriminant score that appears to reflect the internal decision making process. The score showed a clear flexion point that we defined as a moment of outward expression of intention (OEI). This suggests that an alternative decision is made just before an OEI and that intention is expressed in the environment after this OEI in behavior, which in turn suggests that discriminant analysis may be useful in indicating how the brain implements nonverbal social communication. If we could embed the function in a human-machine interfaces, it could enable intuitive, smooth communication between machines and humans.

Keywords: action prediction, decision making, monkey behavior, motion capture, discriminant analysis

1. Introduction

We usually make a decision that returns maximal benefit. At the same time, we try to minimize the social risks accompanying the decision. The adaptive function that balances economical benefit and social risk is called social brain function. However, it is not clear how the function is implemented in the brain.

Recently, neuroeconomists [1, 2] have attempted to reveal the neural mechanism of our decision making process from an economical viewpoint. However, almost no study has placed social issues in experimental design. In reality, human decision making is always influenced by social factors, so that it might be hard to explain the mechanism without considering the social as well as the economic viewpoint. For instance, we often make a decision that provides minimal social risk but moderate economical return. This is because taking lower a social risk often receives a higher priority than enhancing economical benefit. Thus, to reveal the neural mechanism of the decision making process in brain, we have to introduce realistic social factors that require interactive communication in an experimental environment. In a realistic environment, we use both verbal and nonverbal expressions to communicate with others. Nonverbal messages often play key roles on many occasions, because they allow one to transfer intention implicitly and intuitively. Such communication is not only used in humans but is used in other social primates such as monkeys.

In contrast to living creatures, "intelligent" devices, such as computer systems and robots are becoming closer to us daily, and this accentuates the importance of developing intuitive human machine interfaces. Many approaches can improve the interface. For example, the Perceptual User Interface (PUI) [5] allows communication using gestures or voice, and the Brain Machine Interface (BMI) [4] allows the subjects to control external devices by thought. However, these attempts are still in developmental stages and do not capture our intention before the behavior is realized. If we wish to make the interface smoother and more intuitive, devices must be enabled to perceive our implicit intentions before they are made explicit [3].

As a first step in developing such an intuitive interface, we aimed to develop a discriminant function that allows tracking of a monkey's internal decision processes and perception of a given behavioral intention before that behavior is realized.

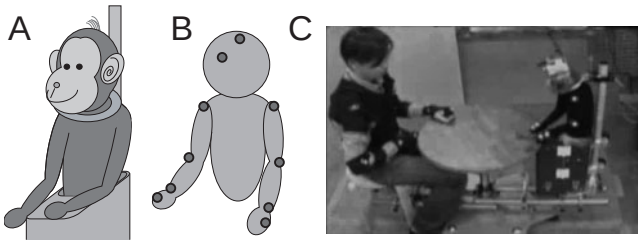

Fig. 1. Experiment setup. (A) Schematic view of the behavioral constraint used. (B) Markers on the monkey's body and head. (C) Actual experiment. The experimenter and monkey sat facing each other across a table and the experimenter provided the task, rewarding the subject with food.

2. Materials and Methods

2.1. Subject and Preparation

One Japanese macaque (male, 5.5 kg) was used throughout the experiment. **Fig. 1** shows a schematic view of the experimental setup. The monkey was seated on a primate chair. The lower half of the body was restrained by an aluminum cover but upper half was restrained only by a collar so that the monkey could move the head, torso and arms freely. It was very important to retrieve the monkey's intention from its behavior because behavioral restraint might distort any expression of natural behavior.

2.2. Recording

We monitored and recorded the monkey's behavior using a motion capture system (Vicon: Vicon-Peaks, Oxford, UK). The monkey was equipped with a motion capture suit with 10 reflective markers were attached (**Fig. 1B**) at the front and back of the head, both shoulders, both elbows, both wrists and both hands. Twelve motion capture cameras were placed around the monkey and used for recording any actions by tracking the marker locations. We also recorded the entire experimental environment using eight conventional video cameras. After the experiment, we reconstructed the three dimensional locations of each marker from motion capture data [6].

2.3. Tasks

We trained the monkey to perform two types of alternative free choice tasks. The experimenter and monkey sat at either end of a table facing each other. In each trial, the experimenter held out both hands to the monkey (**Fig. 1C**). The monkey could choose either the left or right hand to open and each hand held a different quantity of food reward. During the early phase of each trial, a cue indicating the quantity of reward in both hands was presented. The monkey was trained to watch the cue, then decided which hand to reach for; it kept the decision during a preset delay and reached for the hand when it came close. We prepared two different types of free choice tasks: 1-0 and 2-1.

In the 1-0 task, one of the experimenter's hands held a reward but the other did not. The monkey had to detect the correct hand to obtain a reward by observing the sequence of experimenter's actions given as a cue signal. The time course of this task was as follows.

I-1. The experimenter picked up a reward from the food container and placed it on the table in front, in view of the monkey.

I-2. The experimenter placed hands at both sides of the reward (original position) and waited for a few seconds.

I-3. The experimenter started moving either hand to pick up the reward.

I-4. The hand reached to the reward.

I-5. The experimenter picked up the reward with the chosen hand, brought it back to the original position and waited for few seconds.

I-6. The experimenter held both hands out to the monkey.

I-7. The monkey reached to one of the experimenter's hands to get the reward.

I-8. The experimenter opened the hand that the monkey chose.

I-9. The monkey received the reward if the hand was holding it, then ate it and put down its hand.

In the 2-1 task, the experimenter held a piece of reward in one hand, and two pieces of reward in the other. The monkey observed the quantities of rewards in each hand and decided which hand to reach for. The task proceeded was as follows.

II-1. The experimenter picked up rewards in both hands from the food container. One hand held one piece of food and the other held two. After grasping rewards, the experimenter put both hands at the original position as in the 0-1 task. At this point, the monkey did not know which hand was holding more reward.

II-2. The experimenter opened both hands and showed their contents to the monkey for a few seconds. At this point, the monkey could make a decision about which hand to choose.

II-3. The experimenter closed both hands and waited for a few seconds.

II-4. The experimenter held both hands out to the monkey.

II-5. The monkey reached for the hand it had chosen to get the reward.

II-6. The experimenter opened the hand and the monkey grasped the reward.

II-7. The monkey ate the reward and put down its hand.