Chapter 2: General Methods

Subjects

Natural History. The experiments described in the following chapters test the abilities of rhesus macaques (*Macaca mulatta*; hereafter, rhesus). An Old World species of monkey, rhesus are more closely related to humans than are New World monkeys (monkeys indigenous to South America). They are, however, less closely related to humans than the great apes.

Rhesus macaques are thought to have diverged from the human lineage about 35 million years ago (Campbell and Loy, 1996). Rhesus are among 12 species of macaques in the family Cercopithecidea. They are indigenous to much of Southeast Asia, and they inhabit a variety of environments in this area including swamps, mountains, rainforests, and even relatively urban terrains (Lindhburg, 1980).

Adult rhesus range in length from between 47 – 64 cm, not including a 20 – 30 cm tail, and they tend to weigh between 4.5 and 11kg. Adult rhesus demonstrate an obvious sexual dimorphism with males being the larger of the species (Lindhburg, 1980).

Female rhesus monkeys reach sexual maturity at an age of about 3 years, while males reach maturity at about 4 years of age. When male rhesus reach sexual maturity they transfer from their natal social groups, while female individuals tend to remain in the social group into which they were born (Lindhburg, 1980). Thus, rhesus social groups follow a pattern of matrilineal descent. Within these social groups relationships conform largely to a dominance hierarchy. Time spent in a group determines a male's status, and males are generally dominant over females and juveniles in their group. For female

rhesus, matriline determines the majority of one's relative status, and an alpha female is usually the oldest member of a particular matriline.

Experimental Subjects. The rhesus monkeys tested in the experiments presented in this thesis live on the island of Cayo Santiago, off the southeastern coast of Puerto Rico (Kessler and Rawlins, 1986). This field site was established in1939 when 409 rhesus were brought to the island from India. Today, close to 1100 individuals divided into between 9 and 11 social groups inhabit the island.

Cayo Santiago spans approximately 30 acres, over which the rhesus range freely. Terrain on the island includes mangrove swamp, hilly woodland, and pebble beach. Rhesus share the island with several species of crabs, lizards, rats, insects, and tropical birds, however, the monkeys have no natural predators. The monkeys' diet is comprised primarily of Purina monkey chow delivered daily to three feeding corals on the island, though the monkeys also feed on some plants found on the island, as well as mineral rich dirt. A large number of troughs around the island provide the monkeys with unlimited water that is collected via cisterns from rainfall.

The monkeys on Cayo Santiago have been studied since their arrival in 1939, and, therefore, they are rather well habituated to the presence of human observers. Access to the island, however, is limited to researchers and animal caretakers. Monkeys can be identified by ear notches and tattoos comprised of numbers and letters placed on a monkey's chest and inner right thigh. Tattoos proceed in chronological order with letters identifying the year in which an individual was born and numbers identifying its age relative to other monkeys born in the same year. Therefore, tattoos are useful for limiting participation in an experiment to adult subjects.

Several prior studies have examined the spontaneous cognitive abilities of the rhesus of Cayo Santiago in a variety of domains (e.g. Hauser, 1998 in the domain of living things; Santos, Hauser, and Spelke, 2001, in the domain food). A handful of studies have even examined the abilities of these monkeys with respect to numerical representation (Hauser and Carey, in preparation; Hauser, Carey, and Hauser, 2001; Hauser, MacNeilage, and Ware, 1996; Santos, Sulkowski, Spaepen, and Hauser, 2002; Sulkowski and Hauser, 2001;). Nevertheless, the large number of animals living on the island (1100) compared to the small number of animals tested in each of these experiments (between 20 and 50) means that the monkeys are relatively naïve to the experimental tasks presented here. Further, these studies were carried out intermittently, with a period of a few months separating each of these sets of studies.

The experiments presented in this thesis were carried out over the course of several weeks in June and July of 2001, as well as over the course of 2 weeks in November of 2001. The large amount of time over which these experiments were distributed means that for the few individuals who may have been tested in more than one experiment, repeated exposure was spread out over an extensive period of time. Moreover, time spent actually participating in one of my experiments was limited to between 5 and 10 minutes. It seems fair, therefore, to claim that the animals tested in the following experiments were relatively naïve, and that their performance in these tasks is representative of their spontaneous abilities.

Expectancy violation looking time paradigm

Logic. The experiments presented in Chapter 3 employ the expectancy of violation looking time procedure, sometimes known as a looking time task when used in the domain of number. In this paradigm subjects watch as an experimenter performs a series of actions, and subjects' looking time is measured during 2 familiarization trials to these actions, as well as during a test trial revealing the outcome of these actions. The paradigm operates under the assumption that individuals who understand the general physical principles underlying the observed actions will expect the outcome of these actions to conform to these principles. They should, therefore, look for a long time at physically impossible outcomes that are inconsistent with their expectations, just as we look on in amazement when a magician performs an "impossible" trick. In contrast, they should look for a relatively shorter time at outcomes meeting their expectations about the observed events. If subjects do not construct accurate expectations about the events that they observe, then no difference in looking times should be measured between possible and impossible outcomes.

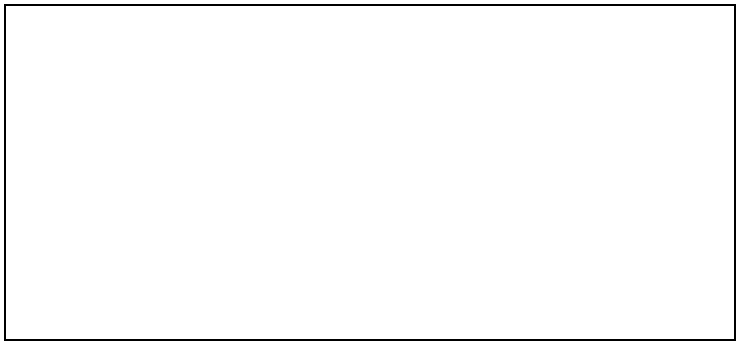
In the domain of number, researchers ask if subjects understand simple mathematical principles by presenting addition and subtraction events that sometimes result in possible outcomes conforming to the rules of arithmetic, and sometimes result in impossible outcomes that do not. In Wynn's (1992) landmark study, preverbal infants who saw a Mickey Mouse doll on a platform, and then saw a second Mickey Mouse placed on the platform behind an occluder (a 1+1 event), looked significantly longer when the outcome of this event was impossible, 1 or 3 dolls, compared to an expected, possible outcome of 2 dolls. This pattern demonstrates that the infants understand the

arithmetic underlying 1+1 = 2, and, also, that they can discriminate between sets of 1, 2, and 3. That is, success in such a looking time transformation task has been interpreted as evidence that an organism can discriminate between the numbers presented in possible/impossible conditions, and that it understands the ordinal relationships among these numbers.

The familiarization trials in these transformation tasks are designed to familiarize subjects to the apparti, the events, and the outcomes in the experiments. There are no impossible outcomes in the familiarization trials. Further, in the experiments presented in Chapter 3, the outcome of the first familiarization trial is always identical in number to the outcome of the test trial, irrespective of whether the test trial is possible or impossible. This means that disparate looking times measured between possible and impossible test trials should only be the product of detecting a violation in the unexpected outcome, and not of a preference for looking at novel displays or displays with a particular number of items.

Apparati and Stimuli. In all expectancy violation experiments, the experimental apparatus consists of a 24 X 14 X 15 inch, three sided, white foam core box with a 12.5-inch screen that can slide in and out of place along a vertical track (figure 2.1). The sliding screen has a small shelf on the side on the inside face of the experimental box and about 5 inches from its bottom. This shelf allows for the surreptitious addition or removal of stimuli for the production of impossible outcomes. For stimuli I use fresh lemons about 2.5 inches in length and of equal looking volume and similar shape. A slice is removed horizontally from each lemon, about 1/8 of an inch from its bottom, so that it

can stand vertically without support. Sessions are recorded with a Sony digital video camera.



Protocol. The procedure for these experiments is identical to that of similar studies employing the looking time paradigm to study rhesus number representations. In particular, the following protocol resembles that of Hauser and colleagues (1996). A team of two researchers – one videotaping the sessions and one presenting the events – searched for adult monkeys who were either alone or in small groups. I only sampled subjects that were not engaged in distracting behaviors such as copulating, fighting, eating or drinking, and were relatively dominant to the individuals in close proximity.

When a test subject was found, the experimenter responsible for presenting the trials set up the apparatus about 3-5 meters away from the monkey. The experimenter responsible for recording the session stood behind the investigator who set up the apparatus; this experimenter recorded the identity of the subject and trial number in the current experiment. The camera focused upon the head and eyes of the subject, and, therefore, the researcher with the camera was unaware of a session's condition: whether it was possible or impossible. This designation was recorded in a notebook after the session ended, along with the subject's number, identification, and whether the trial was run to completion without the monkey leaving or becoming distracted. Therefore,

whether a particular session was possible or impossible was never apparent from the videotape. Consequently, I was able to score trials blind with respect to the condition being tested.

Figure 2.2 pictures the events observed for a sample experiment, 2+2 = 4 vs.6. After the cameraperson began the trial, the experimenter placed the apparatus on the ground with the screen in place so that the subject could not see the contents of the box. Next, the experimenter attempted to attract the subject's attention, and then added lemons to the box with the subject watching. The number of lemons added to the box was identical to the number of lemons that would be added behind the screen in the test trial; however, since a subject never saw how many lemons were in the box, prior to presentation it could not have generated any expectation about the number of lemons behind the screen. For example, if the arithmetical operation tested was 2+2, then 2 lemons were added to the box in view of the monkey during the first familiarization. This was true for both possible and impossible trials.

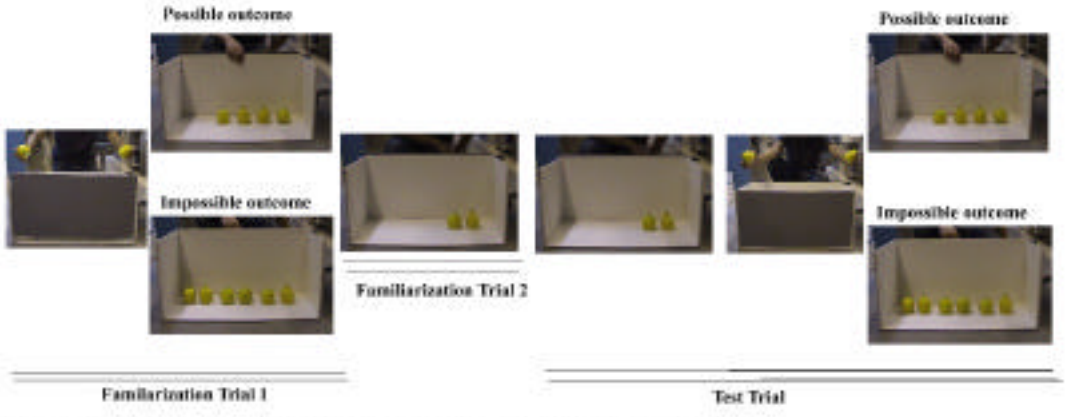


Figure 2.2. Familiarization and test events observed for a sample experiment, 2+2 = 4 vs. 6.

Once lemons were added to the box in the first familiarization trial, the experimenter again attracted the subject's attention, and then lifted the screen out of the

box while saying “Now.” This signaled the beginning of the first familiarization trial. Removing the screen revealed the number of lemons in the box that would be present at the outcome of the test trial. For example, in the experiment involving 2+2 = 4 versus 8, the first familiarization trial revealed 4 lemons in a possible session and 8 lemons in an impossible session.

When the presenting investigator said, “Now”, he looked away from the subject and stared at the ground behind the box. The experimenter with the camera then recorded the monkey as it looked at the apparatus, counting 10 seconds by using the clock in the camera’s viewer. At the end of 10 seconds he said, “Stop,” indicating the end of the first trial.

The investigator presenting the sessions now said, “Trial 2” as he cleared the lemons from the box placing them behind and out view. He then attracted the subject’s attention again, and placed the number of lemons in the box that would be present at the beginning of the test trial before the screen was put in place. For example, in an experiment investigating 3+1 events, 3 lemons were placed in the box during the second familiarization trial, and this was consistent across possible and impossible sessions. The experimenter then said, “Now” as he placed the lemons in the box, and once they were in place, he again looked away from the subject. This marked the beginning of the second trial, and the investigator recording the session again counted 10 seconds before saying, “Stop” to end the trial. The occluding screen was not used in the second familiarization trial.

At the end of the second trial, the investigator presenting the events again cleared the stage placing all lemons behind the box. He attracted the subject’s attention, and

proceeded to place in the box however many lemons were required by the initial portion of the computation that was being studied. For example, in a 3+1 experiment he would place 3 lemons in the box. With the monkey still watching he slid the screen into place, occluding the lemons. He then made sure that the subject was still watching as he placed into the box the number of lemons required by the second piece of the computation of interest. For example, again, in a 3+1 experiment he added 1 lemon to the box behind the occluder. These events were identical in possible and impossible sessions.

During impossible sessions, the experimenter added additional lemons from the shelf on the screen or removed lemons from the box by placing them on the shelf as he put the screen into place. During possible sessions he manipulated the lemons on the shelf so that the two types of sessions looked the same, but he did not surreptitiously add or remove any lemons. Finally, he removed the screen while saying, "Now" to reveal either the expected or unexpected number of lemons in the box. The researcher with the camera counted 10 seconds before saying, "Stop" to mark the end of the session. The experimenter with the camera excluded subjects from the final analysis at this stage if they failed to pay attention for significant portions of the experiment, if they did not look at the apparatus at anytime while the second researcher was saying "Now," or if they seemed distracted or preoccupied. This decision was made before the presenting researcher revealed whether the session included a possible or an impossible outcome. Usually, about 50% of sessions were not included in the final analysis because they were excluded at this stage or because the subject left or was distracted before the beginning of the test trial.

Analysis. Analysis of complete sessions occurred in the Primate Cognitive Neuroscience Lab at Harvard University. Each individual trial within a particular session was assigned a random number. The video camera used on the island was connected to a Macintosh G3 computer via fire-wire, and played the tapes from the island in iMovie digital editing software. Individual trials, from the point a researcher said "Now" to the point at which the other researcher said "Stop," were acquired digitally and named with the random number assigned to each of them in the spreadsheet. These files were randomly assorted and burned onto compact disks.

A second researcher played the files back from the disks in another digital editing program, Adobe Premier 6.0, on a Macintosh G3 computer. This researcher recorded the number of frames in each trial for which the subject was looking at the apparatus. The placement of the apparatus relative to the subject was assumed based on where the subject in the clip looked as the researcher said, "Now." Looking times, in frames, were entered into the spreadsheet by mapping the file names to their corresponding random numbers. In this way, the experimenter coding the video clips had no awareness of whether a particular trial belonged to a possible or an impossible session, or even its relative status within a session as a familiarization or a test trial.