THE EFFECTS OF EXPERIENCE ON TOOL USE BY CAPUCHIN MONKEYS

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The Effects of Experience on Tool Use by Capuchin Monkeys

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Dissertation submitted to the University of St. Andrews for the degree of Doctor of Philosophy

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ABSTRACT

This thesis investigated effects of manipulative experience on tool-using ability of tufted capuchins. Two groups of capuchins were tested on variations of a tool-using task, involving use of an object as a tool to dislodge a reward from a tube. The tasks were modeled after those developed by Visalberghi and Limongelli (1994) and Visalberghi and Trinca (1989). One group of monkeys was provided the opportunity to manipulate task materials without reward; the other group was not.

Experiment 1 required subjects to push a rod through the tube. Experience with task materials improved capuchins' efficiency, evidenced by faster completion of trials. In Experiment 2, short pipes could be combined to create a tool of sufficient length. Due to procedural problems, results were inconclusive. Experiment 3 required subjects to manufacture the appropriate tool. Experience with task materials improved capuchins' performance, evidenced by faster completion of trials, less frequent performance of inefficient behaviors, and decrease in errors across trials. When capuchins' performance was compared with enculturated chimpanzees tested previously on the task (Visalberghi, Fragaszy, and Savage-Rumbaugh, 1995), experienced capuchins performed as efficiently after 15 trials as had chimpanzees originally. In Experiment 4, subjects had to dislodge the reward from a tube containing a trap. Because successful levels of performance were not reached, results were inconclusive. In Experiments 5 and 6, appreciation of object affordances was examined. The capuchins demonstrated an ability to distinguish between functional characteristics of objects.

These results suggest previous claims regarding limitations of capuchin tool-use may have underestimated their abilities. Further, because object experience enhances tool-using ability, previous comparisons of capuchins with enculturated chimpanzees seem to have misrepresented the magnitude of difference in their abilities. However, future research comparing species with the same experiential backgrounds is necessary to

elaborate on differences in cognitive processes underlying capuchin and chimpanzee tool-using behavior.

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CONTENTS

Chapter 1

Introduction

> *". . . an old monkey . . . who having lost his teeth, when nuts are given him, takes a stone into his hand, and cracks them with it one by one" (Darwin, 1801, p.199).*

Erasmus Darwin, grandfather of Charles Darwin, reported one of the earliest observations of nonhuman tool use. He came across a monkey on display at Exeter Change, London, and witnessed this monkey's use of a stone to crack open nuts before consuming them. The monkey that Erasmus saw display this very human-like behavior was a capuchin monkey. A hundred years after this early observation, further accounts of tool use in nonhuman primates began to appear. Because the capacity for tool use has always been considered one of the major achievements of the human species, one which defines man as separate from all other animals, these early observations of tool-using behavior in nonhuman primates have captured the attention of scientists, and have compelled systematic research into the abilities of these species.

In recent years, there has been a wealth of research examining the tool-using behaviors of both monkeys and apes. Most surprisingly, capuchin monkeys (*Cebus spp.*), although phylogenetically quite distant from humans and great apes, have proved to be extremely proficient tool users. The skill with which capuchins use tools in captivity appears to be very similar to that of chimpanzees, the paramount users of tools among great apes. The extensive tool-using repertoire of this species of monkey has raised many questions concerning the cognitive processes that underlie development of this behavior in both man and animal. If capuchins can use tools, does that mean they are equipped with the same level of cognitive understanding of this complex behavior as are chimpanzees, or even humans? Do capuchins comprehend the cause-effect relations involved in using an object as a means to create a desired effect in another object or being? These questions are important when considering the evolutionary development of cognitive ability, as well as for understanding what mental constructs are necessary to be able to produce what appears to be such intelligent behavior.

Before continuing, it is important to take a moment to explain my own usage of the term *cognitive* since this can vary widely between authors. In this thesis, the term is used in the same way as by Tomasello and Call (1997). I examine tool-using behavior from a cognitive approach, as opposed to a behaviorist one; I do not contrast *cognitive* with *animal learning* as opposing theories. Instrumental conditioning, rather, is viewed as a simple cognitive process. Specifically, *cognitive processes* refer to those processes which organize perceptual and conceptual input, and translate that input into functionally meaningful behavioral output based on the perception or understanding of the situation at hand. *Cognitive abilities* refer to the *skill* of organizing or understanding input, and then translating it into appropriate behavioral output.

Relatively few studies have been carried out specifically to examine the cognitive processes underlying capuchins' tool-using behavior and how they differ from those underlying chimpanzees' tool-using behavior. By providing them with tasks designed to assess their appreciation of the functional properties of tool objects, as well as their comprehension of the causal relations involved in tool-using tasks, Visalberghi and Limongelli (1994) and Visalberghi and Trinca (1989) investigated the limits of capuchins' abilities. Their work not only contributed to current knowledge about capuchin tool-using behavior, but also provided a framework for comparing capuchins' abilities with those of other species. Limongelli, Boysen, and Visalberghi (1995) and Visalberghi, Fragaszy, and Savage-Rumbaugh (1995) carried out some of these comparisons with several species of great ape and subsequently made claims about the differences in the cognitive processes underlying each species' behavior. Because these studies have provided the only direct comparison of capuchin and chimpanzee tool-using skill, their findings have been widely accepted as representative of the true differences between capuchins and chimpanzees.

Although cognitive differences may indeed exist between these species, it remains possible that the differences described by Visalberghi and colleagues (Limongelli et al., 1995; Visalberghi et al., 1995; Visalberghi &

Limongelli, 1994; Visalberghi & Trinca, 1989) overestimate the species' difference. This is because the extremely different experiential histories of their capuchin and ape subjects were not taken into account when comparing their abilities. Most of the apes were raised in a human-like cultural environment with extensive human interaction including language exposure and training, and regular access to, as well as encouragement to manipulate, a variety of objects. Rearing in and exposure to this type of environment is commonly referred to as *enculturation* (Tomasello and Call, 1997). Most of the capuchins, on the other hand, were not raised in this manner, but rather in a more typical laboratory setting without extensive human cultural influence. Even the capuchins used in Visalberghi and Trinca's study (1989), which were raised in a human environment, were only exposed to prolonged human contact and human artifacts for a few months before returning to a typical laboratory setting (E. Visalberghi, personal communication, January 11, 1999). Considering that sleep is the predominant state throughout an infant capuchin's first 5 weeks of life, and complex object manipulation (such as, pounding or rubbing of food or objects) does not begin until the third or fourth month of life (Byrne & Suomi, 1995), only a few months of rearing in a human environment is hardly comparable to the apes' lifetime of enculturation. This very brief exposure to human culture, without the extensive human interaction or access to and encouragement to manipulate objects throughout their lifetime that characterizes enculturation, is typically referred to as *hand-rearing*. Recent research has suggested that the influence of human culture may enhance the cognitive development of nonhuman apes (Call & Tomasello, 1996). Similarly, studies concerning the effects of object manipulation experience on problem-solving have found that this can facilitate the development of effective problem-solving strategies (Birch, 1945; Jackson, 1942; Pepler & Ross, 1981; Schiller, 1957; Smith & Dutton, 1979; Sylva, 1977; Sylva, Bruner, & Genova, 1976; Vandenberg, 1981). Therefore, although Visalberghi and colleagues provided useful information about the cognitive limitations of some capuchin monkeys and some enculturated apes, the differences found between them may not be representative of the general differences between these species.

Further examination of the differences between capuchins and chimpanzees is needed before drawing conclusions about their true species differences. The best way to do this would be to "level the playing field", so to speak, and compare capuchins and chimpanzees with more similar experiential backgrounds. This could be done either by examining unenculturated chimpanzees, or attempting to give capuchins some advantage comparable to ape enculturation. In this thesis, I report an attempt to do the latter, by providing capuchins with object manipulation experience before testing their skill on a series of tool-using tasks. Thus, one of the aims of this thesis was to further clarify the limits of tool-using ability in capuchins both with object manipulation experience and without such experience, and to compare their abilities with those of the enculturated chimpanzees tested by Visalberghi et al. (1995).

Additionally, further examination of the effects of object manipulation experience, probably the most salient part of human cultural influence on tool-using ability, is necessary to understand how it facilitates problem-solving in tool-using tasks. The other aim of this thesis, therefore, was to provide further information about the effects of object manipulation experience on tool use. This is also hoped to shed further light on the nature of the problems caused by comparing enculturated, or object-experienced, apes with inexperienced capuchins.

In this chapter, I will first provide some background information about both capuchin monkeys and tool use before discussing the nature of capuchin tool-using ability. I will then briefly review previous research concerning the cognitive processes underlying capuchin tool-using behavior as well as the effects of enculturation and object manipulation experience on problem-solving ability. Finally, I will present the aims of the current study and outline the remainder of the thesis.

Capuchin Monkeys

Habitat and diet

The capuchin monkey studied in this thesis, *Cebus apella*, commonly called the "tufted" or "black-capped" capuchin, is one of seven species of capuchin monkey. Capuchins are a genus of New World monkey, having diverged from a common ancestor with the great apes approximately 35-40 million years ago, widely distributed throughout South America. Although adaptable to a variety of forest types, capuchins prefer canopy-covered forest as a habitat. The distribution of capuchin monkeys extends from Honduras in the north to northern Argentina in the south. The specific distribution of *C. apella* ranges from southern Colombia, east and south to northern Argentina. They are the most widespread of all species of capuchin (Kinzey, 1997).

Capuchins are considered to be frugivore-insectivores (Kinzey, 1997), although they have an omnivorous diet including a wide variety of fruits, nuts, foliage, insects, eggs, and small vertebrates. The diet of *C. apella* in particular is very flexible, as they adapt well to seasonal variation of food sources (Kinzey, 1997; Parker & Gibson, 1977). Capuchins are extractive foragers, capable of manipulating the environment to obtain otherwise inaccessible foods. For example, they will unroll leaves, break open twigs and branches, and pry open the bases of palm fronds to get insects (Kinzey, 1997; Parker & Gibson, 1977), as well as crack open nuts or hard-shelled fruits by striking them with their hands against hard surfaces (Izawa & Mizuno, 1977). The robustness of *C. apella's* jaws and their overall large body size, compared to other capuchin species, are associated with their proficient manipulation of hard-to-open foods (Kinzey, 1997), however they also display a greater dexterity in handling objects than other Neotropical primates which is likely due to their greater thumb robusticity (ratio of thumb metacarpal breadth to length; Fragaszy, Visalberghi, & Robinson, 1990; Westergaard & Kuhn, 1998). Capuchins' proficiency for handling objects in the wild is no doubt reflected in their manipulative propensities in captivity (Visalberghi, 1990; Westergaard, 1994).

Why study *C. apella?*

In addition to being the most widespread species of capuchin in the wild, tufted capuchins are also the most accessible species in captivity. They are known for their object manipulation and tool-using skills, making them the paramount users of tools among monkeys. Due to their accessibility and their propensity for using tools, tufted capuchins are a good species for comparative studies of object manipulation and tool use in nonhuman primates, particularly for comparison with chimpanzees.

Tool Use

Tool use is a special form of object manipulation. Van Lawick-Goodall (1970) defined tool use as "the use of an external object as a functional extension of mouth or beak, hand or claw, in the attainment of an immediate goal . . . related to the obtaining of food, care of the body, or repulsion of a predator, intruder, etc. If the object is used successfully, then the animal achieves the goal which, in a number of instances, would not have been possible without the aid of the tool" (p.195-196). Using a stone as a hammer to crack open a hard-shelled nut in order to gain access to its edible interior, using leaves as a sponge to wipe blood or feces from the body, and using a branch to attack or ward off an intruder are all examples of tool use seen in chimpanzees. It is generally agreed, however, that behaviors which involve an external object attached to its substrate, for example, pounding a hard-shelled nut against a tree (which, unlike a stone, is a fixed object), should not be considered tool use, however similar the behavior. Therefore, Beck (1980) went a step further with the definition to specify that in order to be a tool, the external object "must be free of any fixed connection to the substrate" (p.10).

In addition, Beck (1980) specified that "the user must hold or carry the tool during or just prior to use and must establish the proper and effective orientation between the object and the incentive. The incentive includes alteration of the form, position, or condition of another object, another organism, or the user itself" (p.10). This limits tool behaviors to those in which the animal is directly responsible for establishing the proper physical relations between the tool and the goal. Therefore, a situation in which the animal pulls in a vine to obtain the fruit attached to the distal end would not be considered tool use. Combining all of the elements, Beck defined tool use as "the external employment of an unattached environmental object to alter more efficiently the form, position, or condition of another object, another organism, or the user itself when the user holds or carries the tool during or just prior to use and is responsible for the proper and effective orientation of the tool" (p.10).

Tool manufacture

In addition to using tools, some primates also manufacture tools. Tool manufacture is defined as "any modification of an object by the user or a conspecific so that the object serves more effectively as a tool" (Beck, 1980, p.11-12). Flaking a stone to produce sharper pieces to cut with, stripping a branch of leaves and twigs to produce a sleeker stick to probe with, and crumbling leaves to produce a more absorbent sponging tool are all examples of tool manufacture. Beck divided this behavior into four different modes: (1) *detach* consists of severing the fixed attachment between an environmental object, such as a branch, and its substrate (or another object), such as the tree, so that the object can be used as a tool; (2) *subtract* consists of removing an object or objects, such as leaves or twigs, from the unattached tool object, such as a branch, to create a more effective tool; (3) *combine* consists of connecting two or more objects, such as two short sticks, to produce an effective tool, such as a stick long enough to rake in an out of reach reward; and (4) *reshape* consists of restructuring the object to create a functional tool, such as straightening a bent piece of wire to create an effective raking tool. Tool manufacture is also commonly referred to as tool modification because the object is being modified to create the tool, or to make the tool more effective to use.

Capuchin tool use

Capuchins exhibit many different types of tool use in captivity, however they have only rarely been observed to use tools in the wild (see Beck, 1980; McGrew & Marchant, 1997; Visalberghi, 1990; and Westergaard, 1994, for reviews). The following is a brief review of the various forms of tool use reported for capuchin monkeys in the wild and in captivity (see Table 1.1).

Table 1.1

Tool-Using Behaviors Exhibited by Capuchins

Tool Behavior	**In Captivity**
Nut-cracking (and oyster cracking)	Anderson, 1990; Antinucci & Visalberghi, 1986; Chevalier-Skolnikoff, 1989; Fragaszy & Visalberghi, 1989; Gibson, 1990; Vevers & Weiner, 1963; Visalberghi, 1987; Westergaard, Greene, Menuhin-Hauser, & Suomi, 1996; Westergaard & Suomi, 1993b, 1993c, 1994f, 1997a
Probing (and honey-dipping)	Anderson & Henneman, 1994; Fragaszy & Visalberghi, 1989; Klüver, 1933, 1937; Visalberghi, Fragaszy, & Savage-Rumbaugh, 1995; Visalberghi & Limongelli, 1994; Visalberghi & Trinca, 1989; Westergaard & Fragaszy, 1987b; Westergaard & Suomi, 1993c, 1994b, 1994c, 1994g, 1995a
Ant fishing	Westergaard, Lundquist, Kuhn, & Suomi, 1997
Cutting (or piercing)	Westergaard et al., 1996; Westergaard & Suomi, 1994d, 1994e, 1994f, 1995a, 1995c, 1996, 1997a, 1997b
Weapon use (throwing, clubbing)	Chevalier-Skolnikoff, 1989; Cooper & Harlow, 1961; Gibson, 1990; Romanes, 1892; Westergaard & Suomi, 1994a, 1995d, 1997a
Sponging	Gibson, 1990; Westergaard & Fragaszy, 1987b; Westergaard, Greene, Babitz, & Suomi, 1995; Westergaard & Suomi, 1993a
Container use	Chevalier-Skolnikoff, 1989; Gibson, 1990
Pestle use	Westergaard et al., 1995
Digging	Chevalier-Skolnikoff, 1989; Westergaard & Suomi, 1995b
Lever use	Jalles-Filho, 1995; Romanes, 1892
Raking	Anderson & Henneman, 1994; Byrne & Suomi, 1997; Chevalier-Skolnikoff, 1989; Gibson, 1990; Klüver, 1933, 1937; Parker & Potí, 1990; Romanes, 1892; Warden, Koch, & Fjeld, 1940
Ladder use (boxes or sticks)	Klüver, 1933, 1937
Grooming (wound treatment or body care)	Ritchie & Fragaszy, 1988; Westergaard & Fragaszy, 1987a
	In the Wild
Nut-cracking (and oyster cracking)	Fernandes, 1991; Struhsaker & Leland, 1977
Weapon use (throwing, clubbing)	Boinski, 1988; Chapman, 1986; Chevalier-Skolnikoff, 1990

Tool use in the wild

Reports of capuchin tool use in the wild come from observations of both tufted capuchins (*C. apella*) and white-faced capuchins (*C. capucinus*). Because there are so few reports, the observations of both species will be discussed. In the wild, capuchins customarily use sticks, branches, and other natural objects as weapons by detaching them from their substrate and then throwing them down or dropping them onto humans or other animals who are posing a threat, and they also flail branches at conspecifics or hit them with sticks held in their hands (Boinski, 1988; Chapman, 1986; Chevalier-Skolnikoff, 1990). Additionally, white-faced capuchins have been observed using branches as clubs to attack predators (Boinski, 1988; Chapman, 1986).

While using objects as weapons is the most frequently observed tool-using behavior of wild capuchins, there is anecdotal evidence of other forms of tool use as well. Chevalier-Skolnikoff (1990) observed a white-faced capuchin, foraging for insects in Santa Rosa National Park, detach a dead branch from a tree and then poke it into a small hole in another branch. Upon removal, the monkey put the stick into his mouth, although no insects were seen on the stick by the observer. In Brazil, Fernandes (1991) observed a tufted capuchin opening oyster shells fixed to a mangrove by hitting them repeatedly with what appeared to be a piece of the oyster colony itself. Only one monkey was observed engaging in this behavior, however the group quickly left when they saw the observer so it is possible that others in the group had cracked open oysters while not under observation. Similar behavior has been observed for the opening of palm-fruits and palm-nuts by tufted capuchins. Struhsaker and Leland (1977) observed tufted capuchins pounding nuts together to crack them open, whereas Izawa and Mizuno (1977) found that capuchins typically struck the hard-shelled fruits or nuts against trees to crack them open. Although the latter behavior would not be classified as tool use under the definition given above, it is still worthy of mention because it required skilled manipulation to succeed in cracking open the fruits.

Tool use in captivity

In captivity, capuchins use objects as tools quite regularly. Early observations of capuchin tool use includes Romanes' (1892) accounts of a pet capuchin using a stick to hit humans, poke at the family dog, and pry open boxes, as well as using a variety of objects for raking in food. Klüver's (1933; 1937) early studies provided capuchins with numerous tasks similar to those used by Köhler (1925) and Yerkes and Yerkes (1929) with chimpanzees and were thus the first extensive investigations of a capuchin's ability to use tools. Klüver found that the capuchin succeeded in solving various tasks involving the use of tools to rake in out-of-reach objects, knock down food suspended from the ceiling, push food through a tube or box, as well as modify objects to be used as tools. These behaviors were all performed using a variety of different materials as tools, such as sticks, rakes, boxes, sacks, string, and paper. Three other early accounts of tool-using behavior in capuchins reported the use of a series of eight sticks as rakes to reach increasingly longer sticks before acquiring one of sufficient length for raking in a distant food reward (Warden, Koch, & Fjeld, 1940), the use of a stick as both a club and a poker to hit and jab cagemates who were monopolizing the food (Cooper & Harlow, 1961), and the use of marrow bones left in the cage to crack open nuts (Vevers & Weiner, 1963).

Fifty years after Klüver's (1933; 1937) studies, there was a burst of experimental activity on the tool-using behavior of capuchin monkeys (Anderson, 1990; Antinucci & Visalberghi, 1986; Chevalier-Skolnikoff, 1989; Fragaszy & Visalberghi, 1989; Gibson, 1990; Visalberghi, 1987; Westergaard & Fragaszy, 1987b). The majority of studies on capuchin tool use have served to report the behaviors capuchins are capable of performing. In other words, they simply pointed out that when set a particular task in the laboratory, which encouraged a certain type of tool-using behavior, capuchins did in fact display those behaviors. The importance of the tool-using studies, which now constitute a catalogue of capuchin tool use, was to provide a record of what these monkeys could do in captivity, particularly since these behaviors were not observed in the wild, and to provide a basis for comparing their abilities with those of great apes, particularly chimpanzees.

Tool-using behaviors exhibited by capuchins in captivity include hammering to crack open nuts, probing for honey or other substances, fishing for ants, cutting or piercing through barriers, sponging up liquid, aimed throwing of objects, containing liquid or bits of food, digging for food, pestle-use, lever-use, weapon-use, and treatment of wounds. Capuchins are flexible in their use of materials for a particular tool; for example, they use stones, sticks, bones, wood blocks, or metal bolts as hammers to crack open nuts (Anderson, 1990; Antinucci & Visalberghi, 1986; Chevalier-Skolnikoff, 1989; Fragaszy & Visalberghi, 1989; Gibson, 1990; Visalberghi, 1987; Westergaard, Greene, Menuhin-Hauser, & Suomi, 1996; Westergaard & Suomi, 1993b; 1993c; 1994f; 1997a). They are also flexible in their use of a particular material for many different types of tools; for example, they use sticks as probes (Anderson & Henneman, 1994; Fragaszy & Visalberghi, 1989; Visalberghi & Trinca, 1989; Westergaard & Fragaszy, 1987b; Westergaard & Suomi, 1993c; 1994c; 1995a), rakes (Anderson & Henneman, 1994; Byrne & Suomi, 1997; Chevalier-Skolnikoff, 1989; Gibson, 1990; Parker & Potí, 1990), pestles (Westergaard, Greene, Babitz, & Suomi, 1995), levers (Jalles-Filho, 1995), weapons (Chevalier-Skolnikoff, 1989; Gibson, 1990), digging tools (Chevalier-Skolnikoff, 1989; Westergaard & Suomi, 1995b), fishing tools (Westergaard, Lundquist, Kuhn, & Suomi, 1997), cutting or piercing tools (Jalles-Filho, 1995; Westergaard & Suomi, 1995a), and as tools for grooming wounds (Ritchie & Fragaszy, 1988; Westergaard & Fragaszy, 1987a). Capuchins display persistence in their use of tools; they will continue to work on a task even if they do not succeed at first and will try different means to reach their goal. For example, after unsuccessful attempts to insert a probe into the small opening of a container, Anderson and Henneman (1994) observed a capuchin acquire a more suitable stick to probe with by raking it into reach with the unsuccessful stick. Capuchins also display patience in their use of tools when necessary; they have been observed to wait for ants to climb onto a probe before removing it from the container to eat them (Westergaard et al., 1997).

In addition to using objects as tools in many different contexts, capuchins manufacture tools from available objects if those objects are not already in useable form. For example, they detach branches from trees and subtract the twigs and leaves, creating sleeker probes (Anderson & Henneman, 1994; Westergaard & Fragaszy, 1987b; Westergaard et al., 1997; Westergaard & Suomi, 1994c; 1995a), and they combine leaves or paper towels and then reshape them by crumbling them, creating more effective sponges (Westergaard & Fragaszy, 1987b). Capuchins have also been observed to select more efficient tools from a choice of different objects. For example, Antinucci and Visalberghi (1986) reported a capuchin's selection of a stone as a hammer twice as often as a wood block, and four times as often as a plastic container. Similarly, Anderson and Henneman (1994) noted a capuchin's preference for sticks of the appropriate thickness for probing, over sticks which were too thick for the task. Westergaard and Suomi (1993c) noted capuchins' preference for sticks over stones to extract nut meat from the shells of nuts which had already been cracked (usually with stones). And, when appropriate tools are not available in the vicinity of the tool-using location, capuchins will go into other cages, out of view of the tool-using location, and look for materials, as well as manufacture tools, before returning to the original location to use them (Westergaard & Fragaszy, 1987b).

Finally, capuchins also perform tool-using behaviors which involve the use of more than one tool. For example, they will place one sharp object like a stick or stone (as a chisel) against a barrier and strike it with another stone (a hammer), thus puncturing the barrier and gaining access to the food (Jalles-Filho, 1995; Westergaard et al., 1996; Westergaard & Suomi, 1994d; 1994e; 1994f; 1996). Similarly, capuchins use *tool-sets*, which incorporate the use of more than one type of tool sequentially to achieve a goal. For example, they use stones as hammers to crack open nuts and then sticks as probes or digging tools to extract the nut meat (Westergaard & Suomi, 1993c). They also use sticks as pestles to grind sugar cane and then paper towels as sponges to soak up the sap produced (Westergaard et al., 1995). From the range of tool-using behaviors in which capuchins engage, their flexibility in using many objects as tools in a wide range of contexts is apparent. Further, these behaviors are comparable to those exhibited by chimpanzees.

Comparison with chimpanzee tool use

In the wild, chimpanzees have been observed to perform as wide a range of tool-using behaviors as capuchins do in captivity (see Table I, p.789, McGrew & Marchant, 1997). For example, they use stones to crack open nuts (Boesch & Boesch, 1983; Boesch & Boesch, 1990; Hannah & McGrew, 1987; Sakura & Matsuzawa, 1991; Whitesides, 1985), sticks to fish for ants and termites (Alp, 1993; Boesch & Boesch, 1990; Boesch & Boesch, 1993; McGrew & Collins, 1985; Nishida, 1973; Nishida & Hiraiwa, 1982; Sugiyama, 1995b; Suzuki, Kuroda, & Nishihara, 1995; Tutin, Ham, & Wrogemann, 1995), and leaves to soak up water for drinking (Sugiyama, 1995a; Tutin et al., 1995). Most captive studies with capuchins, in fact, have presented tasks modeled after forms of tool use observed in wild chimpanzees. Chimpanzees also manufacture tools in the same way as capuchins do, for example, by stripping leaves and bark from sticks to create fishing tools. In captivity, chimpanzees perform all of these behaviors as well as a few others, such as raking in out-of-reach objects or using sticks and boxes as ladders (Jackson, 1942; Jordan, 1982; Köhler, 1925; Menzel, 1972; Tomasello, Davis-Dasilva, Camak, & Bard, 1987). Chimpanzees use tool-sets (Brewer & McGrew, 1990; Suzuki et al., 1995); however, unlike capuchins, they have also been observed to use *meta-tools*, or tools which are used to improve the function of another tool. For example, Matsuzawa (1996) observed their use of *wedge* stones to stabilize or level *anvil* stones used in nut-cracking. This behavior thus incorporated the use of three tool objects in a hierarchically more complex behavioral pattern than would be exhibited when simply using a stone to crack open a nut. Therefore, it is possible that chimpanzees are capable of more complex tool-using behaviors than are capuchins, but further examination would be necessary before drawing such conclusions.

Overall, capuchin and chimpanzee tool-using behavior appears to be similar. They perform the same behaviors and seem to do so with the same proficiency. The most apparent difference between the two species is that chimpanzees also perform all these behaviors and a few more in the wild, whereas capuchins have only rarely been observed to use tools in the wild. It is not clearly understood why such differences appear in the wild; however, two alternative explanations have been suggested: (1) capuchins have not been studied as extensively as have chimpanzees, and therefore it is possible that their tool-using activity in the wild has not been comparably represented, or (2) capuchins' arboreal habitat limits their opportunities for using tools (McGrew & Marchant, 1997; Visalberghi, 1993). Despite their similarity to chimpanzees in tool-using skill, however, capuchin monkeys are phylogenetically distant from chimpanzees and this, in combination with the fact that no other species of monkey regularly uses tools either in the wild or in captivity (see Anderson, 1985; Beck, 1980; Natale, Poti', & Spinozzi, 1988; Westergaard, 1988; Westergaard, 1992, for reports of tool use in other monkeys), raises questions concerning whether the cognitive processes underlying this behavior are actually the same in both species.

Cognitive processes underlying capuchin tool use

Anecdotes from tool-using studies have lead some researchers to claim that capuchins may be capable of distinguishing between the properties of objects which are functionally relevant to their use as tools. For example, capuchins have been observed to preferentially select stones for use as tools to crack open nuts when the shells were still intact, and sticks for use as tools to extract the nuts from their shells after they had been cracked, when both stones and sticks were available to chose from (Westergaard & Suomi, 1993c). Similarly, they have been shown to select more efficient tools for a task when provided with objects which would function with less efficiency (Anderson & Henneman, 1994; Antinucci & Visalberghi, 1986). Further, capuchins have been reported to leave the tool-using location to search for tool objects out of sight of that location, and then to manufacture the tools before returning to use them (Westergaard & Fragaszy, 1987b). These behaviors suggest that capuchins are capable of recognizing materials which would make effective tools, and that they are not limited to using objects found within visual range of the goal.

Because these observed behaviors were only anecdotes from studies designed to elicit tool-using behavior, systematic examination of the questions concerning the cognitive processes underlying capuchin tool-using behavior was necessary. Visalberghi and colleagues (Visalberghi et al., 1995; Visalberghi & Limongelli, 1994; Visalberghi & Trinca, 1989) designed and carried out a series of experiments which attempted to do just that. They presented capuchins with increasingly complex versions of a task involving the use of a stick to push a reward through a tube. The first study (Visalberghi & Trinca, 1989) presented capuchins with a simple *tube task*. The task was based on the steel tube test used by Klüver (1933); however, it involved the use of a transparent, plastic tube with a reward in the center. In the first experiment, Visalberghi and Trinca presented the capuchins with a straight stick, readily useable as a tool to push the reward through the tube. Three of the four subjects solved the task. They then presented the capuchins with sticks that had to be modified in order to be used as tools to push the reward through the tube. Three tool-modification conditions were presented: short sticks that had to be used in combination (inserted sequentially into the tube) to reach the reward and push it through the tube; a thick stick or bundle of sticks that had to be broken apart to create a thinner tool which would fit into the tube; and a stick that had two smaller sticks affixed transversally at each end, at least one of which had to be removed in order to insert the tool into the tube. All three subjects successfully pushed the rewards through the tube in all three tool-modification conditions; however, they made numerous errors while doing so. In the first condition, the subjects often inserted the second short stick into the opposite side of the tube from where they had inserted the first stick, thus blocking the reward instead of pushing it through the tube. In the second condition, the monkeys frequently attempted to insert the stick or bundle that was too thick to fit inside the tube. They also broke off splinters and inserted them into the tube even though they were too small to reach the reward. In the third condition, the monkeys attempted to insert the stick without removing the transversals that prevented the stick's insertion. They also removed transversals and inserted them into the tube even though they were too short to reach the reward. Most strikingly, however, the monkeys persisted in making these errors across trials. They were able to solve the task through persistent manipulation of the sticks and tube, but they never seemed to fully comprehend the requirements of the task - the necessity of modifying the sticks in order to produce effective tools for solving the task. Because the capuchins persisted in making errors, and only modified tools after failing to insert them into the tube, Visalberghi and Trinca concluded that the capuchins could not mentally represent the solution to the task and that their actions were not deliberate or foresightful, but rather the result of generic manipulation.

Five years later, another experiment (Visalberghi & Limongelli, 1994) was carried out with the same four capuchins from the first study (the one unsuccessful subject from Visalberghi and Trinca, 1989, had since learned to solve the tube task). In this experiment a variation of the tube task, the *trap-tube* task, was presented in which the tube had a hole in the bottom and an enclosed trap connected to it. This variation increased the complexity of the task by adding a penalty for erroneous actions. By inserting the stick into the side of the tube closest to the reward (the reward being placed to one side of the hole in the tube), the reward is pushed over the hole, thus falling into the trap. Once the reward has fallen into the trap it cannot be obtained and the trial is ended. On the other hand, by inserting the stick into the side farthest from the reward, the reward is successfully pushed out of the tube. Only one monkey was able to successfully push the reward through the tube without it falling into the trap on significantly more than 50% of the trials. However, this rate of success was only achieved after the subject had completed 80 trials. The other three monkeys did not reach a significant level of success on the task even with 140 trials, and continued to push the reward into the trap as often as they pushed it out of the tube. Visalberghi and Limongelli thought the successful subject's performance suggested her ability to represent the outcome of the task, even though it took her 80 trials to be able to do this. In order to assess whether the monkey had solved the task using a representational strategy or an anticipatory strategy (in which she inserted the stick, monitoring the configuration of stick-reward-trap, and modified her actions accordingly), the number of single-insertion versus multiple-insertion trials were assessed for her successful trials. Trials with single insertions would suggest that the side of insertion was chosen before attempting to solve the task (i.e. it was mentally represented). Trials with multiple insertions would suggest that the relations between the tool, trap, and reward were monitored once the stick had been inserted (anticipation of the outcome), and adjusted accordingly. They found that only 42% of her successful trials were performed with single insertions. Therefore, they concluded that the capuchin was unable to represent the outcome of the task in advance, but rather had used an anticipatory strategy to achieve success.

Visalberghi and Limongelli (1994) then presented the same capuchin with further variations of the task in order to examine the nature of her anticipatory strategy. In this experiment, four different conditions were presented: an inverted trap tube - the trap tube was rotated such that the trap was on top of the tube, and therefore no longer effective; alternating trials of the trap tube and the plain tube (the original tube task without the trap); an opaque trap tube - a trap tube covered with an opaque material such that the position of the reward in the tube could only be monitored by looking into the ends of the tube; and an opaque tube - the plain tube covered in an opaque material. In the first condition, the inverted trap tube, the capuchin behaved as if the trap was still effective, inserting the stick into the side of the tube farthest from the reward. On eight of the trials, the monkey even corrected her insertions, which would have lead to failure if the trap were effective. In the second condition, the capuchin behaved as if the plain tube had a trap below it, inserting the stick into the side farthest from the reward. Her behavior during these first two conditions suggested that she was not making predictions based on whether the reward was going to fall into the trap, but rather had adopted some other strategy for success in the original trap-tube task. In the third condition, the monkey successfully solved the task despite the opaque cover on the trap tube. In the fourth condition, she again behaved as if the opaque tube were a trap tube on 70% of the first 30 trials, but then decreased that behavior to 40% of the last 20 trials.

Visalberghi and Limongelli (1994) argued that the results from the first two conditions suggested two things: that the monkey generalized the behavior perfected in the first trap-tube task to the subsequent tasks, and that the monkey lacked an appreciation of the functional differences between the tubes. In other words, the capuchin did not understand that the inverted trap tube, or even the plain tube, had no penalty for inserting the stick on the side closest to the reward. The opaque tube conditions clarified the strategy used by the capuchin to solve the tasks; Visalberghi and Limongelli suggested that she seemed to be using the rule "insert the stick into the opening of the tube farthest from the reward" (p.19). This strategy not only allowed her success on the trap tube, but also allowed her to solve the opaque trap tube when the reward could not be seen through the wall of the tube. The monkey apparently judged the distance of the reward from the end of the tube by looking inside of it, and then was able to correctly choose which side to insert the stick into and solve the task. Due to these findings, Visalberghi and Limongelli concluded that capuchins' success on tool-using tasks does not come from their appreciation of the causal relations between their tool-using actions and the subsequent outcomes, but rather from forming associations between such behaviors as inserting sticks into tubes and acquiring rewards. These associations can then lead to rules for successfully solving tasks, but the monkeys do not necessarily understand why those rules work.

Comparative studies

Visalberghi et al. (1995) carried out another experiment with the tube task in which they compared the performance of common chimpanzees, pygmy chimpanzees, and an orangutan, with that of another group of capuchin monkeys. The tool-modification conditions from their first experiment with capuchins (Visalberghi & Trinca, 1989) were presented again to these subjects, only without the short stick condition. The capuchins' performance on both the thick bundle and stick-with-transversals conditions were similar to the performance of the capuchins in Visalberghi and Trinca's experiment. They persisted in making errors across all 10 trials, such as attempting to insert the whole bundle of sticks or sticks with transversals still blocking their entrance into the tube. The apes' performance on the task was without error for the bundle condition, but for the stick-with-transversals it was more similar to that of the capuchins across the first 5 trials. However, the apes improved their performance by decreasing their frequency of errors in the last 5 trials (at a significance level of $p<.08$).

Based on their different performances, the capuchins' persistent errors versus the apes' improved performance, Visalberghi et al. (1995) concluded that the apes acquired a "fuller comprehension of the task" (p.58) requirements than did the capuchins. Specifically, they claimed that "the persistence of errors suggests that capuchins learned that inserting objects into the tube leads to obtaining food but that they did not understand that the stick must have certain characteristics in order to dislodge the food" (p.58).

Limongelli et al. (1995) also carried out a comparative study of the trap-tube task with chimpanzees. Two of the five subjects reliably dislodged rewards from the trap tube after having completed 70 trials. When they compared the number of single-insertion and multiple-insertion trials, they found that both subjects had significantly more single-insertion trials, suggesting they used a representational strategy to solve the task. Limongelli et al. thus claimed that the subjects' success "may have been based on a causal understanding of the relation between action and outcome, because their performance took into account the position of the trap [in relation to the reward], which is a crucial feature of the trap-tube task" (p.25). Therefore, from this series of studies, it seemed that capuchins are unable to distinguish between the functional and non-functional characteristics of tool objects, nor are they capable of understanding the causal relations involved in the task. Chimpanzees, on the other hand, may be capable of these skills to some extent.

Problems with Visalberghi and colleagues' studies

Although Visalberghi and colleagues (Limongelli et al., 1995; Visalberghi et al., 1995; Visalberghi & Limongelli, 1994; Visalberghi & Trinca, 1989) found some clear differences between the tool-using skills of their capuchin and chimpanzee subjects, these differences may not fairly represent those of capuchins and chimpanzees in general. The main problem with their comparison lies in the differences between the species' experiential histories. All of the apes used in these studies had been raised and housed in human-like cultural environments, including human interactional language training, with extensive exposure to a wide variety of objects and tools throughout their lifetime. All of the capuchin subjects were socially housed in typical laboratory settings, without extensive exposure to a human-like cultural environment or to the same variety of human artifacts. (Visalberghi and Trinca's capuchins had been hand-reared, but only during their first few months of life. The capuchins used by Visalberghi et al., 1995, had not been hand-reared, and their experimental results were similar.)

Therefore, the capuchins in both studies had much less experience manipulating objects than did the apes.

In the light of their different experiential histories, the differences between the species' performances on these tasks are much less impressive. It is hardly fair to compare the abilities of subjects that have had extensive experience manipulating objects with those that have not. Further, the capuchins in the tool-modification conditions of the tube task may have been prevented from even gaining the experience necessary to use the objects efficiently as tools since they were only given 10 trials on the task. Ten trials worth of tool manipulation may not be equivalent to the apes' extensive experience manipulating and using objects. Visalberghi and colleagues (Limongelli et al., 1995; Visalberghi et al., 1995; Visalberghi & Limongelli, 1994; Visalberghi & Trinca, 1989) argued that because the capuchins did not improve their performance on the tool modification tasks, but rather persisted in making errors across all 10 trials, and because only one monkey solved the trap-tube task using a rule-based anticipatory strategy, they were not capable of acquiring an understanding of the causal relations between their tool-using behavior and its outcome. In contrast, the apes which improved their performance on the tool modification task and used what appeared to be a representative strategy to solve the trap-tube task, were thus claimed to have acquired a fuller comprehension of the tasks. However, these individuals may have had a disproportionate advantage and their performance may not be representative of great apes which do not have comparable object manipulation experience. Further examination of the effects of object experience is necessary to assess whether it could have provided the apes with an advantage on these tasks.

Object Experience

A range of studies have shown that experience manipulating objects may facilitate the use of those objects as tools in problem-solving situations. The data that support this theory come from studies of the effects of human cultural influence, as well as from experiments on the effects of object experience on tool-using in both nonhuman primates and human children.

The effects of enculturation on cognitive development

An extensive review of great ape performance in various cognitive domains has suggested that cognitive differences do exist between apes raised in different environments (Call & Tomasello, 1996). In the physical domain, particularly the domain of object knowledge, Call and Tomasello found that apes' knowledge about specific properties of objects depended on the amount of exposure they had had to them. For example, apes exposed to a wider range of objects and tools during their early development displayed a wider range of uses for them in terms of object manipulation and tool use. Call and Tomasello proposed three possible mechanisms to explain these effects: (1) simple exposure to a variety of objects during early development facilitates learning about their properties and perhaps developing generalized skills for exploring new objects, (2) observing humans manipulate and use objects facilitates learning about particular uses for those objects that may not have been discovered through the animal's own manipulation of the objects, and (3) training with the objects may facilitate perception of, or direct attendance to, certain abstract properties of the objects. Therefore, because human-raised apes, unlike apes raised in species-typical environments, are exposed to a greater variety of objects, as well as human manipulation of those objects (including their use as tools), and trained for specific skills with those objects, they acquire a greater knowledge of the properties and functions of many objects, including many that they would not have discovered on their own. Further, Call and Tomasello argued that enculturated apes, home-raised apes treated as intentional individuals in a human-like cultural environment, may acquire a deeper understanding of intentions, or the means-ends structure of behavior, because they are treated as intentional beings. This understanding of the means-ends structure of behavior may lead to the causal understanding of inanimate events as well, such as tool-using behaviors in which the subjects' own behavior is intentional and part of the causal sequence (Tomasello & Call, 1997).

These findings have important implications for comparative work carried out to assess differences between species. In particular, Visalberghi and colleagues (Limongelli et al., 1995; Visalberghi et al., 1995; Visalberghi & Limongelli, 1994; Visalberghi & Trinca, 1989) should have taken into account the different rearing histories of the species they compared. In reference to this problem, Call and Tomasello (1996) suggested that the "supposedly fundamental differences in various aspects of the cognitive development of monkeys and apes may not be as great as many scientists have claimed. Many monkey-ape differences in cognition may result from the fact that the apes producing unique behaviors or skills have been raised in human-like cultural or laboratory environments of a type that monkeys have not been systematically raised or studied in. We thus do not know what enculturated monkeys would do in some of the cognitive tasks at which home-raised apes are so proficient" (p.395).

The effects of object manipulation experience on problem-solving

There is a small body of research that has examined the effects of object manipulation on problem-solving in nonhuman primates. Most studies have found experience to be beneficial to subjects' learning of how to use the objects as tools. Further support for these beneficial effects comes from similar studies with children. Because many of the studies refer to non-goal directed manipulations as "play" (Birch, 1945; Jackson, 1942; Pepler & Ross, 1981; Schiller, 1957; Smith & Dutton, 1979; Sylva, 1977; Sylva, Bruner, & Genova, 1976; Vandenberg, 1981), a word that is avoided in this thesis in favor of more objectively recognized categorizations such as object manipulation, the role of play and exploration in development will be briefly discussed before reviewing the studies.

The role of "play" and exploration in development

Play has typically been thought to be beneficial to development, whether as a means of practicing species-typical behaviors, or of developing innovative and novel combinations of behaviors, which would not be developed otherwise. Play is, therefore, seen as a way of preparing for the use of many behaviors that become necessary later in life (Bruner, 1972 / 1976; Fagen, 1976; Groos, 1898 / 1976; Piaget, 1951 / 1976). Play has also been described as a "means of minimizing the consequences of one's actions and of learning, therefore, in a less risky situation" (Bruner, 1972 / 1976, p.38). Further, it "provides an excellent opportunity to try combinations of behavior that would, under functional pressure, never be tried" (p.38). In other words, play behaviors do not have the same consequences as non-play behaviors and they allow the players to try out novel behaviors or behavioral combinations and discover their effects without being penalized for mistakes. Because of this, many behaviors are tried during play which would not have been attempted otherwise, either for fear of the consequences, or because the attention is focused on attaining a goal, thus inhibiting behavioral creativity. Observations of play in children and nonhuman primates have provided evidence for the benefits of play. For example, van Lawick-Goodall (1968 / 1976) observed young chimpanzees learning how to fish for termites in Gombe. Their fishing behavior developed through a process of playful activities during the first three or four years of life. They first played with materials that could be used for fishing, then practiced manufacturing the appropriate probes, and finally made their first attempts at fishing. Without these behaviors which take place in the context of play, chimpanzees do not develop the effective fishing techniques of adults.

Manipulative experience and problem-solving in nonhuman primates

Early accounts of object manipulation in problem-solving situations come from Köhler's (1925) work with chimpanzees in which they spent a lot of time manipulating the objects before solving many of the tasks. Birch (1945) was the first to systematically study the role of manipulative experience in a problem-solving situation by providing chimpanzees with an opportunity to manipulate sticks between tests on a raking task. When he initially presented a raking task to six chimpanzees, all inexperienced with stick-using tasks, apart from one who had been observed using sticks in non-task situations to flick a light switch outside of her cage, only two of the six subjects solved the task. One was the subject who had previously been observed manipulating sticks; the other accidentally came across the solution when his arm hit against the rake and it caused the food to move. Upon noticing the movement, he pulled the rake towards him and it consequently swept the food within reach.

Birch (1945) then presented the animals with sticks to manipulate for two hours per day over the course of three days. Unlike the rakes, however, the sticks did not have cross bars on the ends. Initially, they examined, handled, and carried the sticks around for short periods of time. Eventually, however, they began reaching for objects while holding sticks in their reaching hands. They seemed not to reach with the stick, but rather with the hand that also happened to be holding the stick. Then, the subjects began poking and touching things with the sticks. And finally, they started reaching out and touching distant objects with the sticks, thus using them as functional extensions of their arms. They were never observed, however, to use the sticks to sweep into reach distant objects.

When Birch (1945) retested the chimpanzees on the raking task, all six subjects solved the task within 20 seconds of presentation by immediately picking up the stick and sweeping the food within reach. Their behavior was markedly different from that during the first test. Apart from one instance by one subject, they no longer attempted to directly reach the food with their hands and they no longer pushed the rakes out of the way. It appeared from these results that the chimpanzees established a pattern of using the sticks as extensions of their arms during their manipulation of them, and thus came to perceive the functional relations existing between the stick, the food, and themselves which were usefully transferred to the raking task. These functional relations were only perceived through their manipulative experience with the objects, and the task could only be reliably solved once the subjects understood these relations.

Two other studies have had similar findings. Jackson (1942) had presented a chimpanzee, who could not solve a raking task, with a stick to manipulate for two days. The chimpanzee never used the stick to acquire distant objects or foods during this period, however when presented with the task again, he spontaneously used the stick to rake in the food. Similarly, Parker and Potí (1990) presented capuchins with a raking task after a period of habituation during which they could manipulate the materials. Only the three subjects who had engaged in manipulation of the sticks during that period used the sticks as rakes to solve the task. It should be noted, however, that the two subjects who did not manipulate the sticks or use them as rakes showed very little interest in them in both situations. Therefore, their failure to solve the task may have been due to lack of motivation.

Schiller's (1957) study comparing chimpanzees' spontaneous manipulations of various objects with their uses of those objects in problem-solving situations also supported the beneficial influence of object manipulation. He found that manipulating the objects seemed to enable problem-solving with them; for example, learning to connect sticks together during non-goal-oriented manipulation correlated with the production of the same behavior in a problem-solving situation. However, he also found that the pressure of reaching a goal seemed to "repress" subjects' ability to recreate the behaviors already developed; either subjects took longer to perform the same behaviors easily performed during the non-goal-oriented session, or they could not reproduce the behaviors at all. Therefore, it seems that manipulating objects allows subjects to experiment with objects and explore their properties and functions in various contexts. However, as Bruner (1972 / 1976) also later observed, when presented with the pressure of obtaining a desirable goal, subjects' behaviors become less flexible.

Children's problem-solving

There is further support for the beneficial effects of object manipulation on problem-solving from studies of human children. When allowed to manipulate task materials before being tested, children typically performed more goal-directed actions (sometimes performing fewer acts to solve the task), showed more persistence in working on the task, and used more organized strategies, beginning with the least complex and gradually increasing in complexity with each subsequent attempt until reaching solution, than did control subjects (Pepler & Ross, 1981; Smith & Dutton, 1979; Sylva, 1977; Sylva, Bruner, & Genova, 1976; Vandenberg, 1981). Sylva and colleagues suggested that manipulative experience facilitates solution on problem-solving tasks for three reasons: (1) working on problem-solving tasks requires self-initiation, and this is encouraged by the object manipulation session, (2) tool invention (or tool manufacture) requires a serial ordering of acts, and during manipulative sessions subjects have the opportunity to explore alternative serial orders of acts with the objects, and (3) manipulating the objects seems to reduce stress, as well as the anticipation of success or failure on the task, and subjects in the manipulative conditions are thus able to continue their flexible behavior in the test session, only in a more goal-directed manner.

As can be seen from these studies, object manipulation experience, whether provided as an experimental condition, or as part of the enculturation of nonhuman primates, seems to have a beneficial influence on subsequent tool-using ability. Previous comparative work which has examined differences in the cognitive processes underlying tool-using behaviors in inexperienced capuchins and experienced chimpanzees may therefore not be representative of differences between the species as a whole. Further examination of the effects of experience on tool-using, as well as the cognitive processes underlying capuchin tool behavior, as compared with chimpanzees, is thus necessary.

Aims of Current Research

The aims of this thesis were: (1) to shed further light on the effects of object manipulation experience on tool-using ability, (2) to clarify the extent of capuchin tool-using ability, and (3) to assess whether enculturation of ape subjects may have confounded previous studies of the differences in cognitive processes underlying capuchin and ape tool-using ability. These aims were carried out through a series of experiments in which capuchin monkeys were tested on the various tube task conditions previously studied by Visalberghi and colleagues (Limongelli et al., 1995; Visalberghi et al., 1995; Visalberghi & Limongelli, 1994; Visalberghi & Trinca, 1989). The variable of object experience was manipulated in each experiment by providing one group of capuchins with the opportunity to manipulate the materials used in the task. The other group of capuchins was not given this opportunity. Manipulative experience was provided in this way both to examine the effects of experience on learning how to solve the basic tube task, and to examine the effects of experience on subsequent performance on all of the tasks.

The first task (Experiment 1, Chapter 2) was a replication of Visalberghi and Trinca's (1989) basic tube task in which a rod had to be pushed through a tube to dislodge a reward. It was expected that capuchins with manipulative experience would first learn to push a rod through the tube earlier, and continue to dislodge the rewards more quickly and more efficiently on subsequent trials than would non-experienced capuchins. The second and third tasks (Experiments 2 and 3, Chapters 3 and 4) were replications of two of Visalberghi and Trinca's (1989) tool-modification conditions of the tube task. In the second task, short pipes had to be combined or inserted sequentially into the tube to reach the reward and push it through the tube. In the third task, the pipes had 'T' shaped caps on the ends which prevented their insertion into the tube, thus the caps had to be removed in order to solve the task. It was expected that in these tasks the experienced capuchins would dislodge the rewards more quickly and more efficiently than would the non-experienced capuchins. The fourth task (Experiment 4, Chapter 5) was a replication of Visalberghi and Limongelli's (1994) trap-tube task, in which a trap was added to the tube such that if the reward was pushed over the trap, it would fall into it and become irretrievable. Considering that only one capuchin in Visalberghi and Limongelli's study solved the task, it was expected that only the capuchins with manipulative experience would achieve success in reliably dislodging the rewards, or at least they would achieve this level of success much earlier than would the non-experienced capuchins. The aim of these experiments was to provide information from which the effects of object manipulation experience on tool-using could be assessed, the limits of capuchin tool-using ability clarified, and the claims made by Visalberghi and colleagues regarding differences between capuchin and chimpanzee cognitive processes reevaluated.

In Chapters 6 and 7, these issues are discussed in relation to the data obtained in Chapters 2 - 5. Additionally, two further experiments are presented in Chapter 6 (Experiments 5 and 6) which tested the hypotheses formulated from the results of Experiments 1 - 4. Note that Experiments 5 and 6 were actually conducted before Experiment 3, however they are not presented until Chapter 6 because they were designed to reinforce the issues being discussed in that chapter. In Chapter 7, the capuchins' performance in Experiment 3 is compared with that of chimpanzees tested on the same tool-modification condition of the tube task by Visalberghi et al. (1995). And finally, in Chapter 8, some future directions for research are discussed.

Chapter 2

Experiment 1: Learning a novel tool behavior

To examine the effects of object manipulation experience on capuchins' tool-using abilities, this first experiment used the most basic tube task introduced by Visalberghi & Trinca (1989), which involved pushing a straight rod through a clear tube to dislodge a reward placed in the center of the tube (see Figure 2.1). The variable of object experience was manipulated by providing one group of capuchins, the *experience group*, with the opportunity to manipulate the objects used in the task. The other group of capuchins, the *non-experience group*, was not given this opportunity. By testing both groups of capuchins on the same task, it was possible to examine the effects of this prior experience on learning how to perform a novel tool behavior, pushing a tool through a tube to dislodge the reward, and on subsequent performance of that behavior.

A set of pre-defined, task-oriented behaviors were recorded in this experiment. The behaviors included any direct manipulations with the apparatus or tools used in the task, either individually or in combination with one another. They incorporated both the behaviors scored in Visalberghi and Trinca's (1989) study with the same task, and behaviors noted during a pilot session in which the apparatus was presented to a group of capuchins that were not used in this study. The purpose of the pilot session was to compile a list of task-oriented behaviors and to make sure the apparatus was sturdy enough to withstand the capuchins' curiosity and rough handling.

Based on previous research (Birch, 1945; Jackson, 1942; Pepler & Ross, 1981; Schiller, 1957; Smith & Dutton, 1979; Sylva, 1977; Sylva et al., 1976; Vandenberg, 1981) which has suggested that manipulative experience with objects enhances the use of those objects in a problem-solving situation, the following predictions were made for the current experiment. It was hypothesized that the capuchins that received manipulative experience with the task objects would learn to use a tool to push the reward out of the tube, thereby solving the task, before the capuchins without such experience. It was also hypothesized that once this had been learned, the experienced

Figure 2.1.Iko pushes a rod through the tube to dislodge the fruit reward.

capuchins would work more efficiently on the task by dislodging rewards more quickly and making fewer errors.

Method

Subjects

The subjects used in this experiment were eight tufted capuchin monkeys (*Cebus apella*) housed in two captive social groups at the National Institutes of Health Animal Center (see Table 2.1). The experience group subjects were four monkeys from a social group of 10 animals (see Table 2.2): an adult male, Zephyr; two juvenile males, Garth and Java; and a juvenile female, Jesse. They were housed in a double indoor cage (each cage measuring 2 m wide x 1 m deep x 2 m high) joined by a sliding cage door. Testing of the subjects took place in only one of these cages, which will be referred to as the "test" cage. Each cage contained perches in addition to a variety of enrichment objects, which included balls, cups, chains, and pipes large enough to crawl into. The enrichment objects were a selection of plastic and rubber toys for the monkeys to manipulate, chew, or climb on, thus enhancing their repertoire of activities in captivity.

The non-experience group subjects were four monkeys from a social group of 19 animals (see Table 2.3): an adult male, Creepshow; a juvenile female, Lee; and two juvenile males, Squeak and Iko. They were housed in an enclosure consisting of three outdoor cages and one indoor room (each measuring 2.5 m wide x 3 m deep x 2.5 m high) each joined to the adjacent one by a sliding guillotine door. Testing of the subjects took place in one of these outdoor cages and this will be referred to as the "test" cage. All four cages contained perches in addition to a selection of enrichment objects, which in the outdoor cages included balls, cups, swings, and barrels.

A variety of enrichment objects were always present in both group's cages (i.e. before and during these experiments) and were not removed during testing. Food (commercial monkey chow) and water were available ad libitum, and fresh fruit, nuts, and seeds supplemented their diet. All subjects had been exposed to tasks involving the use of tools (see Table 2.1).

Table 2.1

Subject Information

Group	Subject	Sex	Age (yrs)	Tool Experience[a]
Experience	Zephyr	M	18.7	1,2,4,5
	Jesse	F	5.2	1,5
	Garth	M	4.1	3,5
	Java	M	2.8	5
Non-experience	Creepshow	M	7.0	2,5
	Lee	F	5.3	2,5
	Squeak	M	4.0	6
	Iko	M	3.5	5,6

[a] Tool experience: 1)Sponging (Westergaard & Suomi, 1993a); 2)Nut cracking (Westergaard & Suomi, 1993b); 3)Cutting (Westergaard et al., 1997); 4)Bimanual tube dipping (Westergaard & Suomi, 1994b); 5)Syrup or ant dipping (Westergaard, Lundquist, Haynie, Kuhn, & Suomi, 1998; Westergaard et al., 1997; Westergaard & Suomi, 1994c; 1994g); 6)Raking (Byrne & Suomi, 1997)

Table 2.2

Social Group Information for Experience Group Subjects

Animal	Sex	Age (yrs)
Ivan	M	17.0
Zephyr	M	18.7
Jasmine	F	11.0
Jesse	F	5.2
Java	M	2.8
Jumper	M	0.1
Greta	F	20.2
Garth	M	4.1
Gracie	F	2.8
Gizmo	M	0.7

Note. Family members' names begin with the same first letter and offspring are listed immediately below their mother.

Table 2.3

Social Group Information for Non-Experience Group Subjects

Animal	Sex	Age (yrs)
Othello	M	17.0
Hamlet	M	15.4
Creepshow	M	7.0
Lucy	F	11.0
Little Ricky	M	6.7
Lee	F	5.3
Liddy	M	4.3
Lorena	F	2.7
Lexus	M	0.4
Isabella	F	16.0
Isuzu	M	5.6
Iko	M	3.5
Ito	M	1.7
Shinade	F	12.4
Shasta	M	6.7
Squeak	M	4.0
Sagan	M	born mid-study
Mocha	F	4.0
Magic	F	2.7

Note. Family members' names begin with the same first letter and offspring are listed immediately below their mother.

Subject selection

Individual subjects were not randomly assigned to each condition, but rather, the social group as a whole was assigned to the experience and non-experience conditions. This was done because subjects could not be removed from their social group to carry out this series of experiments. Individual separations caused too much stress and subjects could not be permanently removed from their family group to form a new social group. Consequently, if a subject in one social group was given the opportunity to manipulate the task materials, the other subjects in that group would also have access to the materials. It was necessary, therefore, for all subjects in the same social group to be in the same experimental condition.

To ensure that the animals in each social group were similar with respect to manipulative propensity, they were compared before the experiment began. During 26 half hour sessions (one session per animal above the age of 0.5 years in each group), plastic pipes (each 30 cm in length and 1.3 cm in diameter) were provided to the group in order to supplement the enrichment objects already available in their cage such that each animal had access to at least one object, not being manipulated by another animal, at all times. Between five and fifteen pipes were provided to each group in order to meet this criterion. During each session, the object manipulations of one animal were observed at 15 second intervals. One-zero sampling was used to record object contact and object combination behaviors. *Object contact* was defined as manual manipulation of any unattached object in the cage. *Object combination* was defined as manual manipulation of an unattached object in combination with another unattached object, in which both objects are clearly in contact with one another. After each session, the pipes were removed from the cage.

Differences in frequency of object contact and object combination between the groups were analyzed using the Mann-Whitney U test. There were no significant differences between the experience and non-experience groups for frequency of object contact (mean frequency per animal = 44.0 for the experience group vs. 36.5 for the non-experience group; U=65.0, ns) or object combination (mean frequency per animal = 0.8 for the experience group vs. 1.3 for the non-experience group; *U*=68.0, ns).

The eight subjects selected for the current experiment were those animals in each social group that learned to push a tool through the tube within the first few test sessions of the experiment. Therefore, all animals in both social groups had the opportunity to work on the task at the onset of the experiment. However, four animals in each group dislodged a reward within these first few sessions, apart from Squeak who solved in the fifth session when he finally gained access to the task, and these eight animals became the subjects for the current, and subsequent, experiments. The other animals in each social group were not given another opportunity to work on the task due to time constraints imposed by other researchers' schedules and the limited amount of time for carrying out this series of experiments, as well as the interference of social factors such as restricted access to the apparatus for some individuals by more dominant animals. In fact, the majority of non-subject animals in each group were either uninterested in the task, too young to be tested as they were still dependent on their mothers, or too low in dominance to be allowed access to the task by other group members.

Once the eight subjects were selected (four from each group), the pre-experiment manipulative data were reanalyzed to ensure that the selected subjects in each group did not differ in manipulative propensity. No significant differences were found between the selected subject groups for frequency of object contact (mean frequency per subject = 43.5 for the experience group vs. 55.0 for the non-experience group; *U*=6.0, ns) or object combination (mean frequency per subject = 1.8 for the experience group vs. 2.3 for the non-experience group; *U*=6.5, ns). Additionally, the data were analyzed to ensure that subjects did not significantly differ in manipulative propensity from non-subject animals in their social groups, and therefore were no more likely to manipulate the task objects than were the animals who were not selected as subjects. No significant differences were found between the subjects and non-subjects for frequency of object contact (mean frequency per animal = 49.3 for the subjects vs. 34.6 for the non-subjects; *U*=56.0, ns) or object combination (mean frequency per animal = 2.0 for the subjects vs. 0.7 for the non-subjects; U=53.0, ns).

Counter Balancing

There was no counter balancing of subjects in the experimental conditions; subjects remained in the same condition, experience or non-experience, throughout the series of experiments. As was previously mentioned, subjects housed in the same social group could not be removed from that group and were therefore exposed to the same condition. Had it been possible to divide subjects in each condition and switch half of them to the other condition for each subsequent experiment, it may have been possible to examine the effects of cumulative object experience as compared to experience from objects in a specific experiment. The practicalities, however, dictated that differences between cumulative and non-cumulative experience were not a focus of this thesis. Additionally, for both Visalberghi et al.'s (1995) and Limongelli et al.'s (1995) chimpanzees, object experience was an accumulation of experience manipulating objects throughout their lifetime, and thus experience accumulated across experiments in this study more closely approximates theirs.

Another counter balancing option would have been to alternate experimental conditions for each group in each experiment, instead of keeping conditions consistent throughout the series of experiments. However, this would have confused the issue of manipulative experience such that after Experiment 2 both groups would have had approximately the same amount of object exposure. Even though different tools were used in each of the first three experiments, the tube apparatus remained the same and the solution to the task, after tool modification, also remained the same. Therefore the only effects which could have been studied were those of the specific experience with the new tool, which was not the focus of the thesis. Instead, I aimed to study the effects of manipulative experience on tool-using ability in a manner which was comparable to the manipulative experience obtained by the chimpanzees' previously studied. Their experience was with more than just the tool being used in the task they were presented. Their experience encompassed a wider variety of objects than were used in this experiment, however the salient ones were most likely those similar to, or related to, the tasks they were tested on. Thus, experience with all of the objects used in these experiments more closely approximates the experience of the chimpanzees than would experience with only one tool. In these experiments, therefore, the effects of manipulative experience on tool-using ability are examined by keeping the experimental groups consistent throughout the experimental series.

One must keep in mind, then, that the effects of experience in all of the subsequent experiments may be due to both cumulative experience from manipulating objects in each study, as well as specific experience manipulating the objects particular to a study. Because the tools are different in Experiments 1 - 3, and the tube is different in the Experiment 4, both of these effects are possible, and in many cases may be difficult to distinguish between.

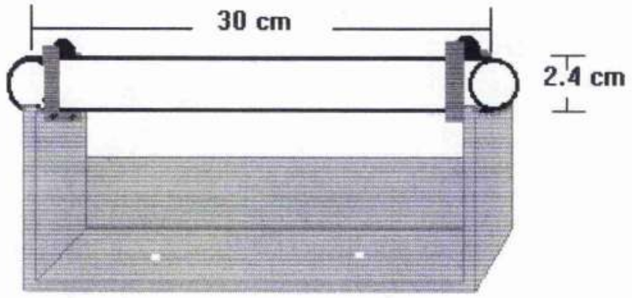
Materials

The apparatus was a transparent plastic tube (30 cm in length and 2.4 cm in diameter) mounted in a frame. Because of differences in cage structure, a different frame was used to mount the tube in each group's cage (see Figure 2.2). Despite the difference in appearance of each frame, there were no differences in the function of or access to the tube in either frame. The objects provided for use as tools were all plastic rods (each 30 cm in length and 1.3 cm in diameter). They had been created by placing caps on the ends of PVC pipes, to keep rewards from becoming lodged inside the hollow pipes. The enrichment objects were also available for use, although they were not specifically provided for the experiment.

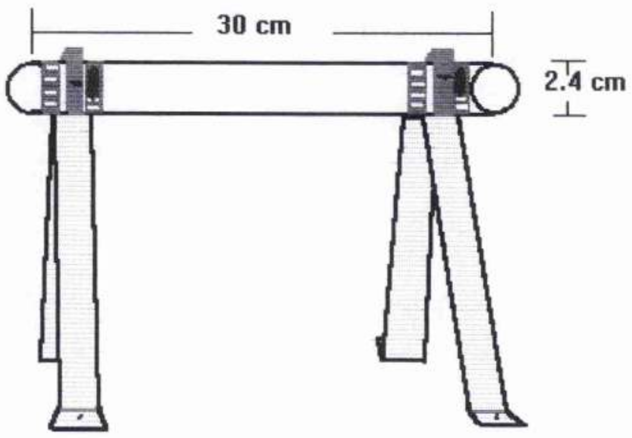
Procedure

Procedural constraints

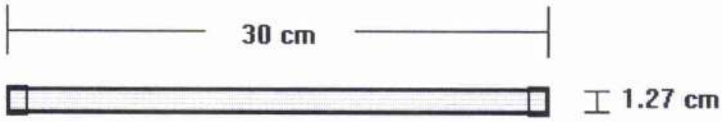
In an ideal experimental environment, subjects would be individually separated from their social groups for testing. The animals in this experiment, however, were not trained to be separated from their groups and



(a)



(b)



(c)

Figure 2.2. a) Tube apparatus used with the experience group; b) tube apparatus used with the non-experience group; c) rod provided for use as a tool.

became stressed when separations occurred. Therefore, to keep stress to a minimum, separations were only performed when necessary. Due to this constraint, all animals in each social group had access to the task during many of the manipulative sessions and at least the first two test sessions. Once a subject completed 50 trials on the task during test sessions, they were then separated out of the test cage during subsequent sessions to allow other subjects increased access to the apparatus. Additionally, some non-subject animals were temporarily removed from the test cage to reduce interference with the task. A separation was made by encouraging the animals to go into either the test or non-test cage and then closing the sliding door adjoining the two cages. When these separations were performed for manipulative sessions, an attempt was made to keep all subjects who had not completed their 50 trials in the test cage. When these separations were performed for test sessions, at least one subject was kept in the test cage. However, due to the difficulties with separating animals that were not trained to be separated, priority was given to removing from the test cage those subjects who had completed 50 trials. Whichever subjects then remained in the test cage were given the manipulative or test session. This meant that subjects in the experience group who were still being provided with the opportunity to manipulate the task materials, and subjects in both groups who were still being tested, were not always present in the test cage for every session.

Non-subject animals were typically present in the test cage during manipulative and test sessions. During most test sessions, interference with the task by non-subject animals was not a problem because either the subject or a dominant non-subject animal would threaten away the other animals when they approached the apparatus. However, because these animals were present in the cage, it was common for subjects to lose their task rewards to the non-subject animals. Due to this problem, solution of the task was defined as dislodging the reward from the tube by inserting a tool into the tube and pushing it through. Solution did not require that the subject obtained the reward and ate it. Therefore, a subject could solve the task on a trial in which another animal received and ate the reward pushed out of the tube by the subject. When more than one subject animal was in the test cage during testing, and both subjects manipulated the apparatus during a trial, the trial was counted for the subject who inserted the tool into the tube and pushed out the reward, thereby solving the task. The trial was not counted for the subject who only touched the tube or manipulated the tool.

A second procedural constraint was that the experiment was originally intended to be carried out with the apparatus mounted outside the subjects' cage for both manipulative and test sessions. The purpose of an external mount was to ensure that the cage did not have to be opened every trial to rebait the tube, thus risking the escape of animals. With the experience group, four manipulative sessions and three test sessions were carried out with the apparatus mounted on a test cart attached to the outside of their cage. No subject inserted a rod into the tube during these test sessions, and few rods were contacted with the tube during either the manipulative or test sessions. It was too difficult for subjects to pass their arms through the cage bars and line up the rods to insert them into the tube when the apparatus was mounted outside the cage. Therefore, a decision was made to change the procedure by mounting the apparatus inside the cage where subjects would have greater access to it. Subjects could easily combine the rods with the tube when the apparatus was mounted inside the cage and their movements were not restricted by cage bars. Because the animals in the experience group did not dislodge any rewards and were restricted from doing so during those first three test sessions, and their behavior towards the apparatus was similar to that during manipulative sessions, these initial test sessions were treated as manipulative sessions. These sessions are denoted as manipulative sessions 1, 3, and 6 for the experience group and only differed from manipulative sessions 2, 4, 5, and 7 in that the tube was baited with a reward. Manipulative session 8 and all subsequent manipulative and test sessions were conducted with the apparatus mounted inside the test cage. For the non-experience group, the apparatus was mounted inside the cage on all test sessions.

Manipulative sessions

The experience group subjects received a series of 30-minute manipulative sessions before each test session. During the manipulative sessions, the apparatus was mounted on the floor inside the cage (except for sessions 1 through 7 as explained above), but no reward was provided. Five rods were placed on the cage floor and they were resupplied if subjects threw them out of the cage during the session. A set of pre-defined behaviors were recorded during the session (see Table 2.4) and qualitative notes including information about the types of tube and rod manipulations made provided supporting details. Manipulative sessions typically lasted 30 minutes, however session 10 only lasted for 20 minutes because subjects broke the tube apparatus and sharp pieces of plexiglass had to be removed from their cage.

The schedule of manipulative and test sessions for each subject was dependent upon their success during each test session and their cooperation during separations. All four subjects were present for the first 12 manipulative sessions. On all subsequent manipulative sessions, Garth was separated out of the test cage because he had completed his testing. Due to the aforementioned difficulties with separations, not all of the remaining subjects were present for each subsequent manipulative session. Table 2.5 shows the final schedule of manipulative and test sessions for each subject. Sessions are numbered separately for each subject. The non-experience group was not provided with any manipulative sessions. They were tested on a continuous testing schedule until 50 trials had been completed by each subject (see Table 2.6).

Test sessions

Test sessions were conducted with both groups. At the beginning of each test session, the apparatus was mounted inside the cage. It was secured to the floor in the experience group's cage, and to a wire shelf in the non-experience group's cage because it could not be secured to their concrete floor. Five rods were provided on the cage floor or shelf next to the apparatus and they were resupplied if subjects threw them out of the cage

Table 2.4

Operational Definitions of Behaviors Recorded During Manipulative Sessions

Behavior:	Operational Definition:
Manipulation	Manual handling of an object.
Tool manipulation	Manipulation of the rod.
Manual contact	Touching the tube with one or more hands.
Tool contact	Making contact with the tube by means of the rod.
Tool insertion	Putting the rod into the tube.
Non-tool object contact	Making contact with the tube by means of an object other than the rod.
Bout	A behavior performed several times in succession without break or interpolation of a behavior of another type.

Table 2.5

Schedule of Manipulative and Test Sessions for Experience Group Subjects

Garth	Java	Zephyr	Jesse
manipulative 1	manipulative 1	manipulative 1	manipulative 1
manipulative 2	manipulative 2	manipulative 2	manipulative 2
manipulative 3	manipulative 3	manipulative 3	manipulative 3
manipulative 4	manipulative 4	manipulative 4	manipulative 4
manipulative 5	manipulative 5	manipulative 5	manipulative 5
manipulative 6	manipulative 6	manipulative 6	manipulative 6
manipulative 7	manipulative 7	manipulative 7	manipulative 7
manipulative 8	manipulative 8	manipulative 8	manipulative 8
test 1: trials 1-24	**test 1: (no trials)**	**test 1: (no trials)**	**test 1: (no trials)**
manipulative 9	manipulative 9	manipulative 9	manipulative 9
manipulative 10	manipulative 10	manipulative 10	manipulative 10
manipulative 11	manipulative 11	manipulative 11	manipulative 11
manipulative 12	manipulative 12	manipulative 12	manipulative 12
test 2: trials 25-50	**test 2: trial 1**	**test 2: (no trials)**	**test 2: (no trials)**
	manipulative 13	manipulative 13	manipulative 13
	manipulative 14	manipulative 14	manipulative 14
	manipulative 15	manipulative 15	manipulative 15
	test 3: trials 2-24	**test 3: trial 1**	manipulative 16
	manipulative 16	manipulative 16	**test 3: trials 1-17**
	manipulative 17	manipulative 17	manipulative 17
	test 4: trials 25-50	manipulative 18	manipulative 18
		manipulative 19	**test 4: trials 18-50**
		test 4: trials 2-27	
		manipulative 20	
		manipulative 21	
		manipulative 22	
		test 5: trials 28-50	

Note. Manipulative sessions 1 - 7 were conducted with the apparatus mounted outside the cage. Manipulative session 8 and subsequent manipulative and test sessions were conducted with the apparatus mounted inside the cage. All manipulative sessions lasted 30 minutes, except for session 10 which lasted 20 minutes due to breakage of the apparatus.

Table 2.6

Schedule of Test Sessions for Non-Experience Group Subjects

Creepshow	Lee	Iko[a]	Squeak[b]
test 1: trials 1-16	test 1: (no trials)	test 1: (no trials)	test 1: (no trials)
test 2: trials 17-48	test 2: trials 1-5	test 2: (no trials)	test 2: (no trials)
test 3: trials 49-50	test 3: trials 6-8	test 3: trials 1-3	test 3: (no trials)
	test 4: trials 9-12	test 4: trials 4-9	test 4: (no trials)
	test 5: trials 13-43	test 5: trials 10-18	test 5: trials 1-5
	test 6: trials 44-50	test 6: trials 19-49	test 6: trials 6-9
		test 7: trial 50	test 7: trial 10
			test 8: trials 11-12
			test 9: trials 13-38
			test 10: trials 39-50

[a] Iko's access to the apparatus was restricted during the first two test sessions by the more dominant subjects, Creepshow and Lee. [b] Squeak's access to the apparatus was restricted during the first three test sessions by the more dominant subjects. Squeak's access to the apparatus was restricted in tests 4, 7, and 8 by dominant, non-subject cagemates. On test 7, Squeak was removed from the test cage after one trial because of threats from a dominant cagemate.

Table 2.7

Operational Definitions of Behaviors Recorded During Test Sessions

Behavior:	Operational Definition:
Tool insertion	Putting the rod into the tube.
Success	Dislodgment of the reward from the tube after having pushed a rod through.
Errors:	
Direct reach	Direct manual reaching towards the reward in the tube.
Tool contact	Non-insertion rod contact with the tube.
Object insertion	Putting a non-tool object into the tube.
Incomplete insertion	Incomplete insertion of the rod into the tube, failing to contact the reward.
Incomplete push	Incomplete push of the reward, failing to dislodge it from the tube.

during the session. The apparatus was baited out of subjects' view before each trial by covering it with a lab coat and then placing a food reward (a slice of banana, apple, or grape) in the center of the tube. A trial began when the lab coat was removed from the apparatus and ended when a subject dislodged the reward from the tube. A set of pre-defined behaviors (Table 2.7) and *trial completion times*, the amount of time taken to dislodge the reward from the tube from the start of a trial, were recorded for each trial. Qualitative notes including such information as who took the reward after the task was solved, what types of tube and rod manipulations were made, subject's attention level while working on the task, techniques used to secure the reward during a trial, and any outside distractions or social interference during the trial provided supporting details.

Test sessions had no fixed duration because they depended upon subject cooperation, feeding schedule, and the schedule of other researchers at the lab. Test sessions typically lasted between 60 and 120 minutes, with the longest session lasting 240 minutes. The number of trials completed during each session varied depending on the subject, the length of each trial, and social factors interfering with testing such as the occurrence of fighting or mate soliciting in the social group.

Analysis

The two-tailed Mann-Whitney U test was used to examine differences between groups for trial completion times, errors, reward loss or acquisition, and strategies used to secure rewards. The Page Test for Ordered Alternatives was used to examine performance trends across blocks of trials (Siegel and Castellan, 1988). Blocks consisted of 10 trials each for purposes of comparison with Visalberghi and Trinca's (1989) study using the same task.

Results

Manipulative sessions

During manipulative sessions subjects showed varied amounts of interest in the rods and the tube. During the sessions before their first test trials, subjects spent more time engaged in tool manipulation and manual contact with the tube than they did in tool contact with the tube (see Figures 2.3, 2.4, and 2.5). After completing their first test trial, both Garth and Jesse increased their frequency of tool contacts with the tube. Java and Zephyr, however, increased their frequency of tool contacts with the tube after Garth's first test trial instead of after their own first test trials. Figure 2.6 depicts subjects' tool insertions across the manipulative sessions. The first tool insertion made during manipulative sessions always occurred following that subject's first test trial. That is, subjects only inserted the rod into the tube during manipulative sessions after having done so during a test session.

The amount of rod and tube manipulation during manipulative sessions varied between subjects and sessions. Because the schedule of manipulative and test sessions was different for each subject, a direct comparison of the frequency of manipulations for each subject could not be made. However, Figure 2.7 shows the frequency of total object manipulations (tool manipulation, tool insertions, and manual, tool and non-tool object contacts with the tube) for each subject across that subject's manipulative sessions. Garth and Java made the highest frequency of total manipulations during manipulative sessions. They are also the youngest of the four subjects in the experience group. Zephyr, the oldest subject, made the lowest frequency of total manipulations during manipulative sessions. Across all manipulative sessions, both before and after each subject's first test trial, tool manipulation made up the highest percentage of all subjects' manipulations. Tables 2.8 and 2.9 show the percentage of each type of object manipulation out of the total number of manipulations performed by each subject before and after completing their first test trials. A statistical comparison of the frequency of manipulations for each subject could not be made because not only was the schedule of manipulative and test sessions different for each subject, but subjects' manipulations during manipulative sessions could not be divided into comparable units such as trials.

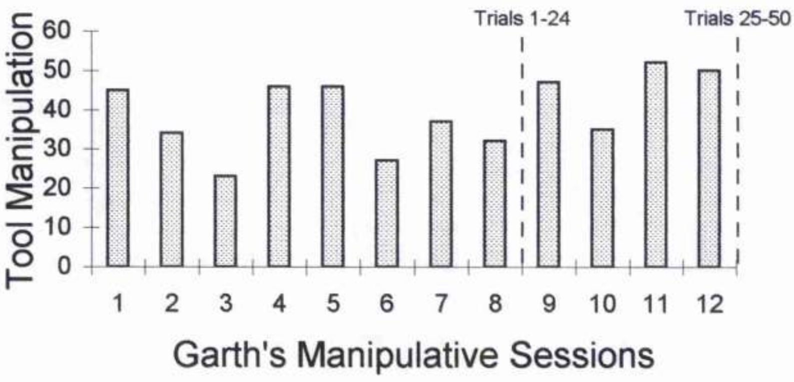


Figure 2.3a. Number of tool manipulation bouts for each of Garth's manipulative sessions. Note that dotted lines show when test trials were completed.

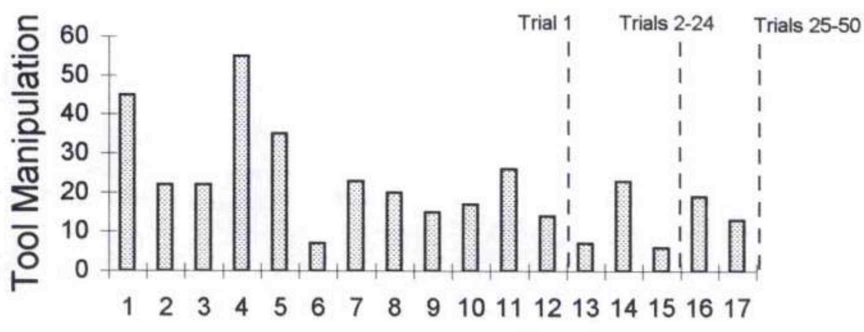


Figure 2.3b. Number of tool manipulation bouts for each of Java's manipulative sessions.

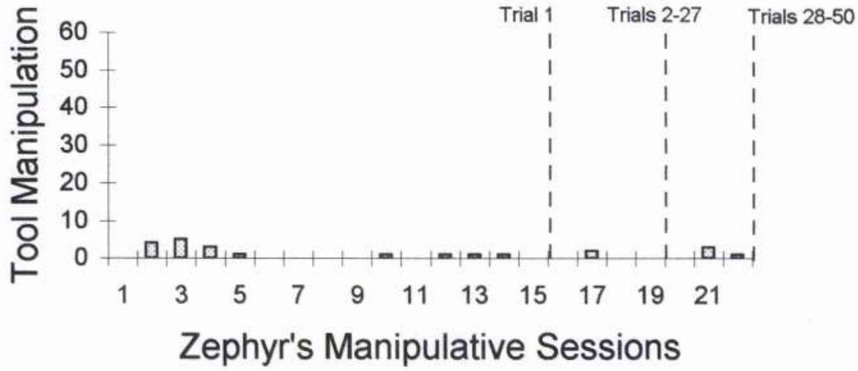


Figure 2.3c. Number of tool manipulation bouts for each of Zephyr's manipulative sessions.

Figure 2.3d. Number of tool manipulation bouts for each of Jesse's manipulative sessions.

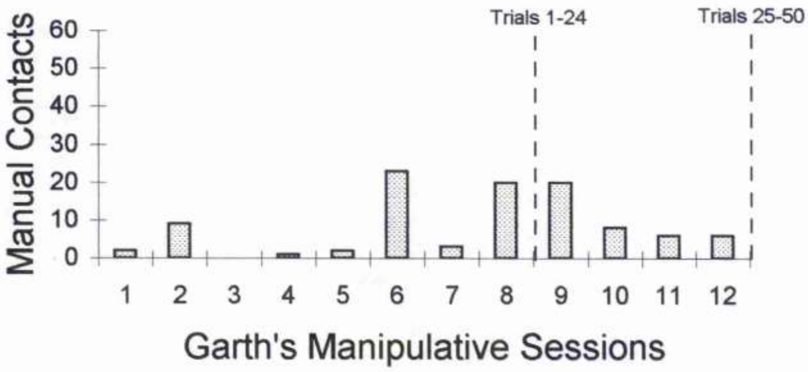


Figure 2.4a. Number of bouts of manual contact with the tube for each of Garth's manipulative sessions.

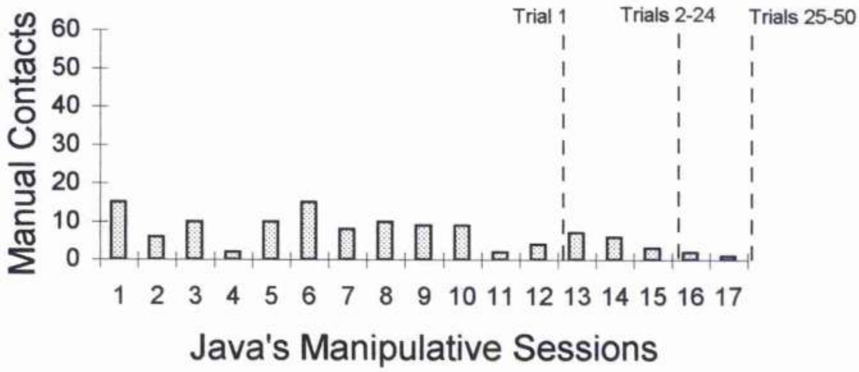


Figure 2.4b. Number of bouts of manual contact with the tube for each of Java's manipulative sessions.

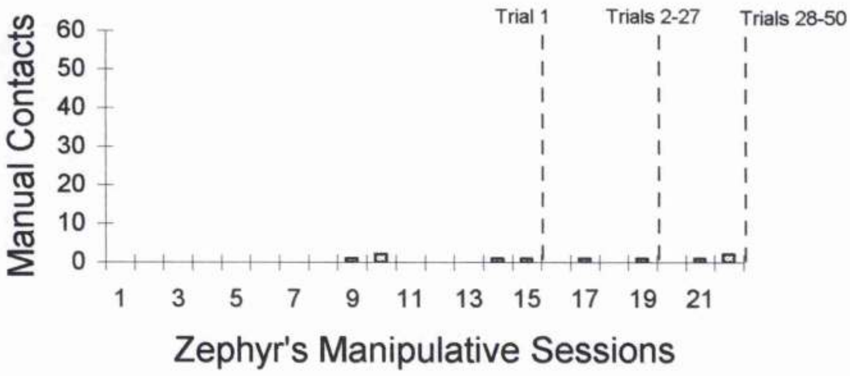


Figure 2.4c. Number of bouts of manual contact with the tube for each of Zephyr's manipulative sessions.

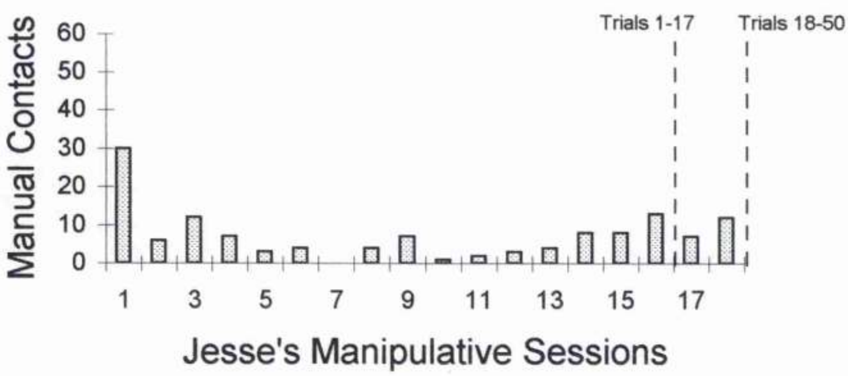


Figure 2.4d. Number of bouts of manual contact with the tube for each of Jesse's manipulative sessions.

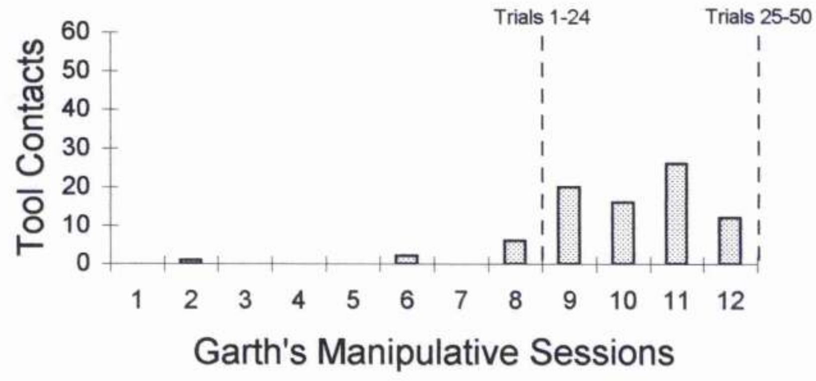


Figure 2.5a. Number of bouts of tool contact with the tube for each of Garth's manipulative sessions.

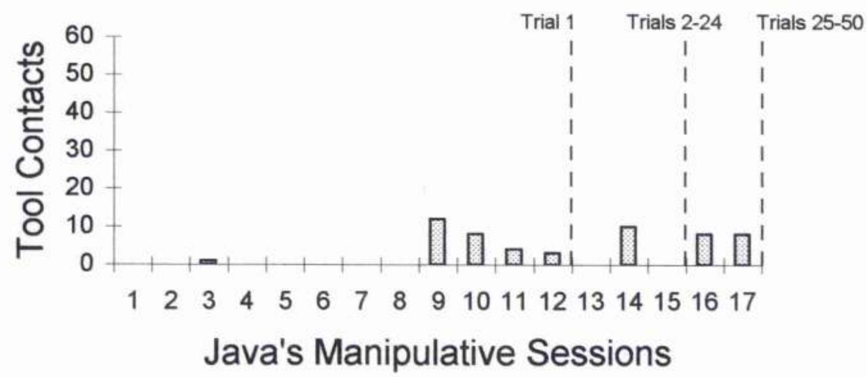


Figure 2.5b. Number of bouts of tool contact with the tube for each of Java's manipulative sessions.

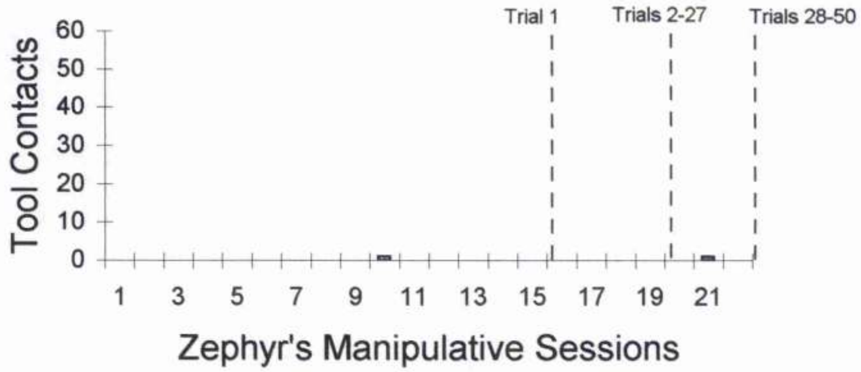


Figure 2.5c. Number of bouts of tool contact with the tube for each of Zephyr's manipulative sessions.

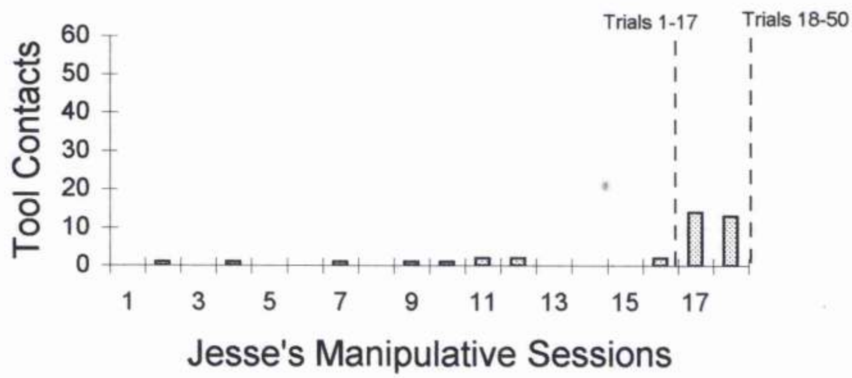


Figure 2.5d. Number of bouts of tool contact with the tube for each of Jesse's manipulative sessions.

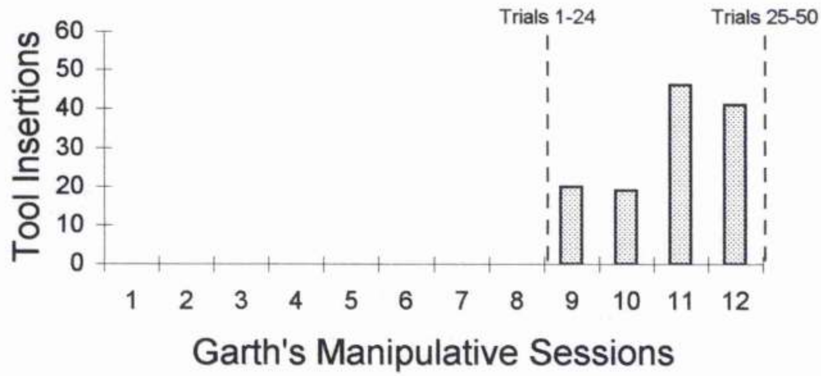


Figure 2.6a. Number of bouts of tool insertion for each of Garth's manipulative sessions.

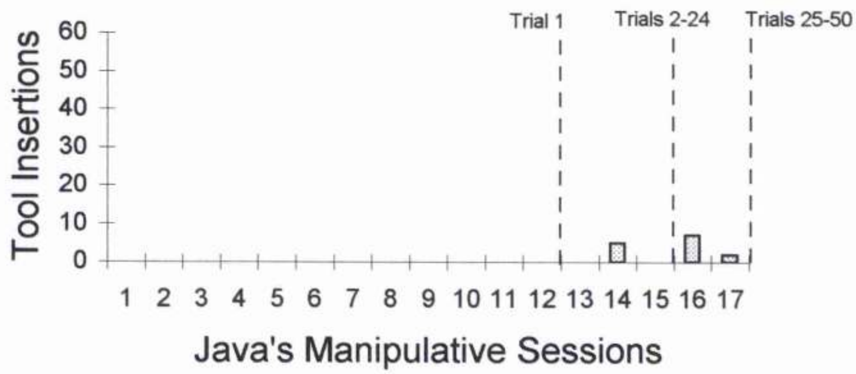


Figure 2.6b. Number of bouts of tool insertion for each of Java's manipulative sessions.

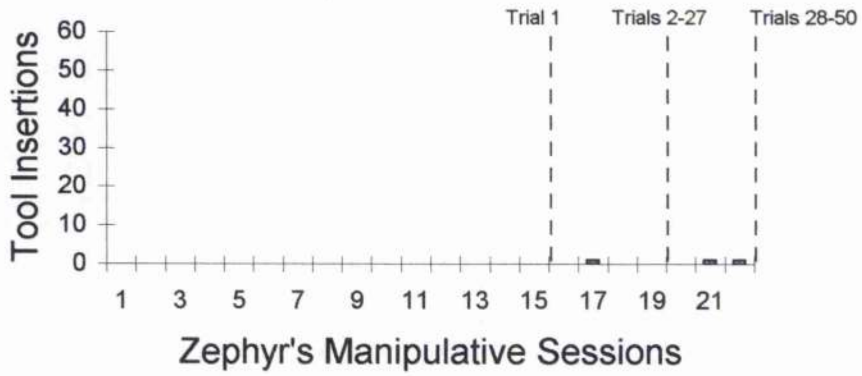


Figure 2.6c. Number of bouts of tool insertion for each of Zephyr's manipulative sessions.

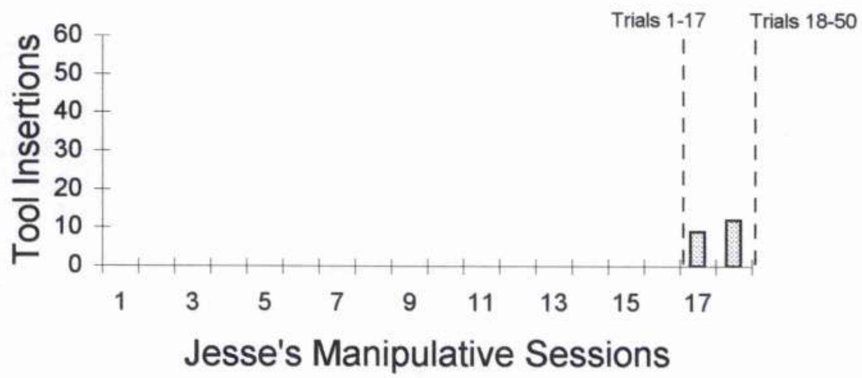


Figure 2.6d. Number of bouts of tool insertion for each of Jesse's manipulative sessions.

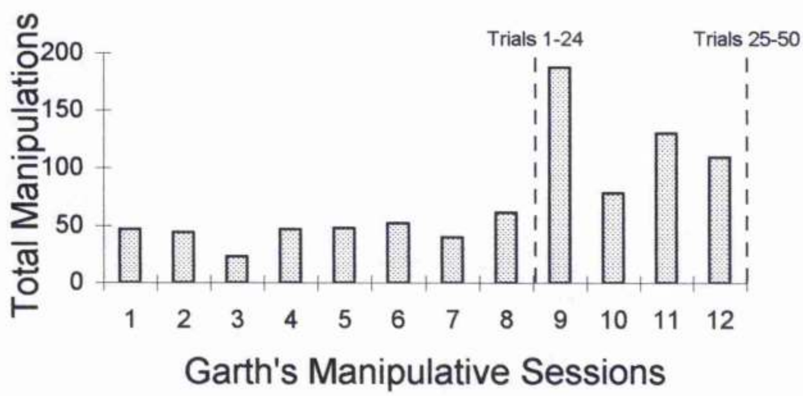


Figure 2.7a. Total number of bouts of object manipulation for each of Garth's manipulative sessions.

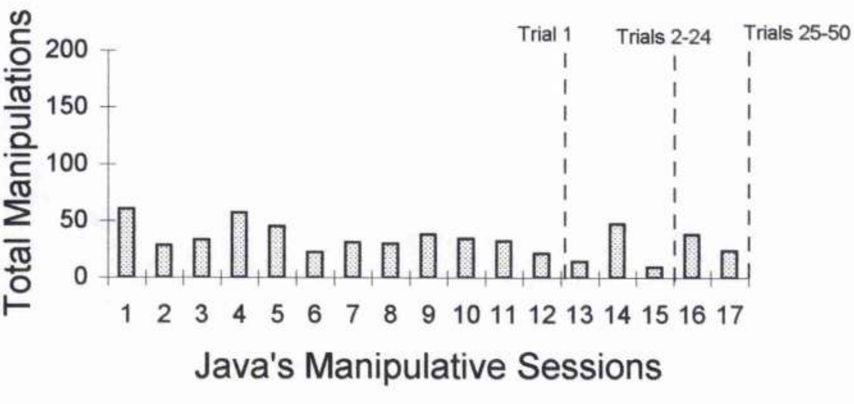


Figure 2.7b. Total number of bouts of object manipulation for each of Java's manipulative sessions.

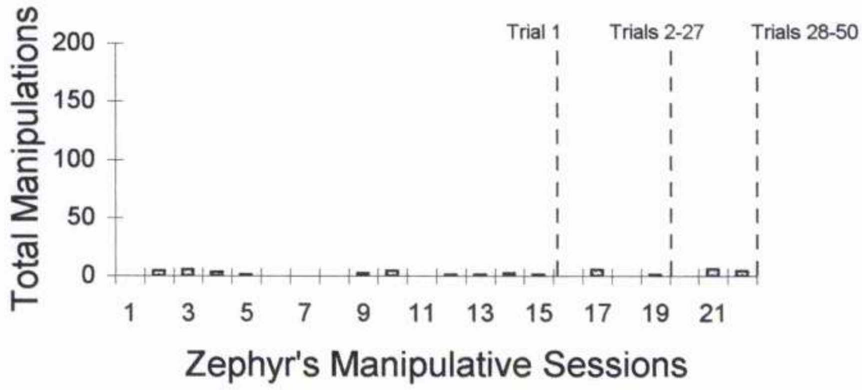


Figure 2.7c. Total number of bouts of object manipulation for each of Zephyr's manipulative sessions.

Figure 2.7d. Total number of bouts of object manipulation for each of Jesse's manipulative sessions.

Table 2.8

Percentage of Each Type of Object Manipulation Out of Total Manipulations

Made Before First Test Trial

Subject	Tool Manipulation	Manual contact	Tool contact	Non-tool object contact	Tool insertion
Garth	80.1 (290)	16.6 (60)	2.5 (9)	0.8 (3)	0.0 (0)
Java	69.8 (301)	23.2 (100)	6.5 (28)	0.5 (2)	0.0 (0)
Zephyr	70.8 (17)	20.8 (5)	4.2 (1)	4.2 (1)	0.0 (0)
Jesse	50.4 (127)	44.4 (112)	4.4 (11)	0.8 (2)	0.0 (0)

Note. Percentages of each type of object manipulation for each subject are calculated from the total number of manipulations made by that subject before completing their first test trial. The actual number of manipulations is given in parenthesis.

Table 2.9

Percentage of Each Type of Object Manipulation Out of Total Manipulations

Made After First Test Trial

Subject	Tool Manipulation	Manual contact	Tool contact	Non-tool object contact	Tool insertion
Garth	43.2 (184)	9.4 (40)	17.4 (74)	0.4 (2)	29.6 (126)
Java	51.5 (68)	14.4 (19)	19.7 (26)	3.8 (5)	10.6 (14)
Zephyr	37.5 (6)	31.2 (5)	6.3 (1)	6.3 (1)	18.7 (3)
Jesse	44.6 (54)	15.7 (19)	22.3 (27)	0.0 (0)	17.4 (21)

Note. Percentages of each type of object manipulation for each subject are calculated from the total number of manipulations made by that subject after completing their first test trial. The actual number of manipulations is given in parenthesis.

Learning to solve the task

First solution

At the start of testing subjects generally approached the apparatus without delay and most made initial unsuccessful attempts to obtain the reward. Since all subjects had access to the apparatus during the first two test sessions and more than one subject usually had access during subsequent sessions, subjects could manipulate the apparatus and rods even while another subject was working on a trial. Therefore, initial attempts to obtain the reward were often performed before a subject's own first test trial, during other subject's test trials. These initial unsuccessful attempts included direct manual reaching towards the reward either from the outside of the tube or by inserting their hand into the end of the tube, biting the tube around the position of the reward, and making non-insertion tool contacts with the tube. Each subject learned to use the rod to push the reward through the tube in their own way. These *first solutions* cannot be quantified, but are better represented through a description of each subject's behavior. The following are descriptions of each subjects' first solutions.

> Experience group. Garth's first solution occurred during the first test session. He began by manually reaching towards the reward both from outside the tube and with his hand inserted in the tube. After about 210 seconds, Garth began to manipulate the rod in combination with the tube by touching it to the outside of the tube. After about another 60 seconds, Garth manipulated the rod near the opening of the tube. He looked at the end of the tube, but he did not insert the rod. Approximately 210 seconds later, after having left the apparatus to manipulate the rod, Garth returned, inserted it into the tube, and pushed it a couple of times slowly until the reward was dislodged. Garth watched one of his conspecifics take the reward from the tube. He then went around to the end of the tube from which the reward was retrieved and looked inside the tube.
>
> Java's first solution occurred during the second test session after having made many manual and tool contacts with the tube during Garth's trials. The trial started with Garth inserting a rod into the tube without pushing it far enough to solve the task. Another animal in the group removed the rod from the tube and Java made attempts to reach the reward by inserting his hand in the tube. After these unsuccessful attempts, Java then picked up the rod, inserted it into the tube and dislodged the reward.

Zephyr's first solution occurred during the third test session. After a number of attempts to reach the reward manually during Garth's trials, Zephyr approached the apparatus while the other subjects were grooming, inserted a rod into the tube and solved the task. After solution, another subject took the reward while Zephyr continued to investigate the end of the rod and look through the end of the tube.

Jesse's first solution also occurred during her third test session. After inserting her hand into the tube and failing to reach the reward, Jesse inserted a rod and pushed it very slowly until the reward fell out of the tube. She went to the end of the tube from which the reward fell and looked at it before taking the reward.

Non-experience group. Creepshow was the first subject to dislodge a reward from the tube, doing so within 10 seconds after the onset of the first trial. As the trial began, Creepshow picked up a rod, inserted it into the tube and pushed out the reward. Despite his speed of solution, though, he failed to retrieve the reward himself. One of his conspecifics took the reward from the end of the tube just as Creepshow pushed it out.

Lee's first solution occurred during the second test session. After numerous attempts to reach the reward manually and to manipulate the rod in combination with the tube during Creepshow's trials, Lee eventually inserted the rod correctly and dislodged the reward. She did not seem to notice one of her conspecifics take the reward from the end of the tube, however. Instead, Lee looked at the end of the rod, inserted it into the tube a second time, removed it and licked banana residue from the end.

Iko's first solution occurred during the third test session. After having made manual attempts to reach the reward during Creepshow's trials in the first session, Iko inserted a rod into the tube during the first 30 seconds of his first trial. With this insert, though, Iko did not reach the reward. He inserted the rod again, reached the reward this time, but did not push it far enough to dislodge it. After removing the rod, Iko investigated its end and licked banana residue from it. Iko then left the apparatus to feed on chow. He did not return until approximately 300 seconds later at which point he unsuccessfully attempted to insert a piece of chow into the end of the tube. After about another 60 seconds, Iko picked up a rod, inserted it into the tube and dislodged the reward.

Squeak's first solution also occurred during his third session of testing. It was actually the fifth session during which he was present in the test cage, but only the third session during which he had access to the apparatus and was not threatened away by more dominant animals for the entire session. Squeak had few opportunities before his first trial to manually manipulate the tube because his access to the task had been limited. When Squeak finally had the opportunity to approach the apparatus he grabbed a rod and quickly inserted it into the tube, dislodging the reward and retrieving it himself.

As can be seen from the above descriptions, each subject completed their first trial in their own way. Creepshow's solution is impressive because he dislodged the reward so quickly without having had any experience with the task. It is also interesting to note that some of the more dominant subjects such as Lee, Garth, and Java made more attempts to solve the task before their first solution than did the other subjects. In contrast, Zephyr and Squeak, the least dominant animals in their respective groups, each solved the task as soon as the opportunity was available. Once they had access to the task, that is, as soon as the more dominant animals were not paying attention, Zephyr and Squeak immediately inserted the rod and dislodged the reward.

Another interesting behavior was that some of the subjects licked and investigated the rods as if they expected the reward to be on the end of it when they withdrew it from the tube. This suggests a transfer of the behavior learned for probing tasks to their solution behavior at the beginning of this experiment. In previous probing tasks (Westergaard & Suomi, 1994c), the subjects had inserted sticks or metal bolts into an enclosed apparatus containing syrup and then withdrawn the probes to lick syrup from the ends. In the current experiment, two non-experience group subjects, Lee and Iko, licked banana residue from the end of the rod after having inserted it into the tube and withdrawn it from the end of insertion. Lee did not seem to notice the animal that took her reward from the other end of the tube, and instead looked at the end of the rod that she had withdrawn from the tube as if expecting the reward. Iko also did this after his second insertion, but then reinserted the rod and successfully pushed out the reward. One experience group subject, Zephyr, also focused his attention on the end of the rod after withdrawing it from the tube, while another animal took the reward, but unlike Lee and Iko, he did not lick the rod.

The effects of experience

Latencies to first solutions were analyzed to determine if experience provided an advantage for learning to push the rod through the tube to dislodge the reward. Because more than one subject was present during most test sessions, and had access to the task while another subject was working on a trial, manipulations made with the tube during other subjects' trials, and those made during their own first trial, were counted as *solution attempts* made before their first solution. No subject made tool contact with the tube on more than two of another subject's trials before their first solution. When subjects were rank ordered for quality and quantity of solution attempts before their first solution (by assigning different ranks to each type of solution attempt; see Table 2.10), no difference was found between the groups (mean rank for solution attempts before first solution = 5.5 for the experience group vs. 3.5 for the non-experience group; Mann-Whitney U test, U=4.0, ns). Total *elapsed time* to first solution was also examined. The elapsed time for each subject only counted the time spent manipulating the tube during other subjects' trials before their own first solution as well as the time for their own first trial. Time spent in the test cage during test sessions but not spent manipulating the tube was not counted because in many cases subjects did not have access to the apparatus when there were more dominant animals in the cage. Also, any instances during each subject's first trial in which the subject's access to the task was restricted by dominants was not counted. There was no significant difference in elapsed time to first solution between the groups (mean time = 573.5 seconds for the experience group vs. 386.8 seconds for the non-experience group; U=5.0, ns; Figure 2.8).

The frequency of tool contact with the tube, and the combined frequency of manual, tool, and non-tool object contacts with the tube before first solution were then examined (Figures 2.9 and 2.10). The experience group had a significantly higher frequency of tool contact than did the non-experience group (mean frequency of tool contact per subject = 4.8 for the experience group vs. 1.0 for the non-experience group; U=0.5, p<.05). The experience group also had a higher frequency of combined contacts, although the difference was not statistically significant (mean frequency of

Table 2.10

Ranking of Solution Attempt Types

Behaviors listed in decreasing rank order
Incomplete insertion or incomplete push
Tool contact at end of tube, as if to insert
Non-insertion tool contact
All other tube contact

Note. The solution attempts made before each subject's first solution were evaluated. A subject whose total attempts achieved a lower rank would be scored as having reached first solution before a subject whose total attempts achieved a higher rank.

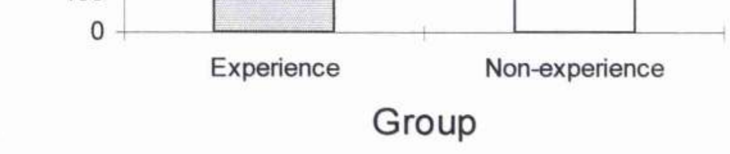


Figure 2.8. Elapsed time (±*SE*) to first solution averaged across subjects for each group.

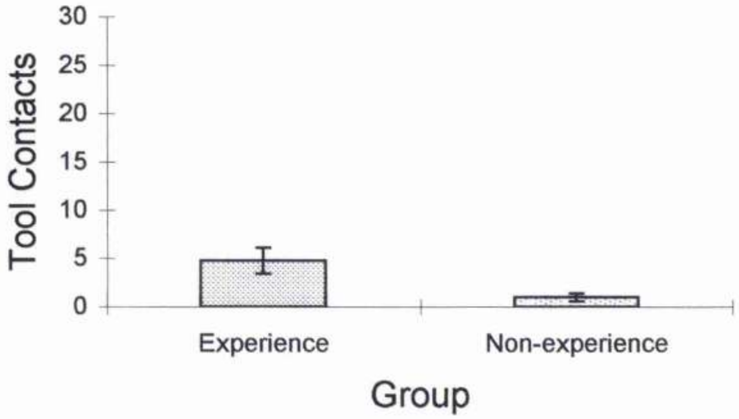


Figure 2.9. Number of tool contacts with the tube (±*SE*) before first solution averaged across subjects for each group.

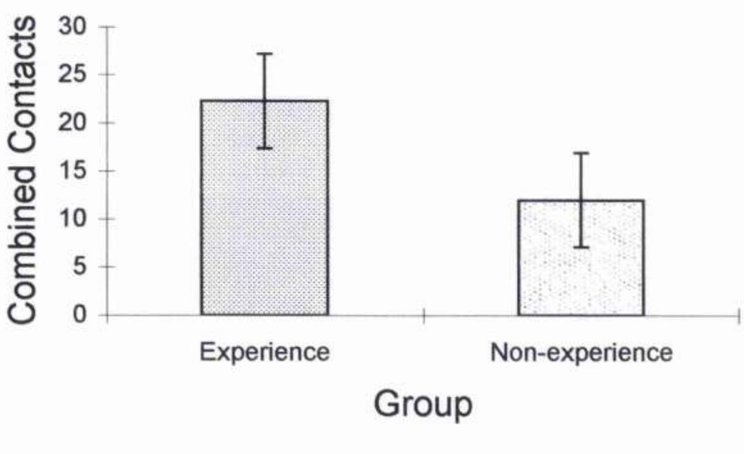


Figure 2.10. Number of manual, tool, and non-tool object contacts with the tube (±*SE*) before first solution averaged across subjects for each group.

combined contact per subject = 22.3 for the experience group vs. 12.0 for the non-experience group; U=2.0, p=.08).

The effects of experience on subsequent trials

After having learned how to dislodge rewards from the tube, subjects continued to work on the task readily throughout testing. However, the non-experience subjects took longer to dislodge rewards than did the subjects with experience, although the difference was not statistically significant (mean time per subject per trial = 58.9 seconds for the non-experience group vs. 33.0 seconds for the experience group; U=2.0, p=.08; Figure 2.11). Further, the non-experience group's trial completion times decreased significantly across blocks of trials (Page Test for Ordered Alternatives, L=207, p<.01). The experience group's trial completion times decreased as well, although the trend was not significant (L=195, ns). It should also be noted that the experience subjects' completion times stabilized after 10 trials (mean time per subject across trials 11-50 = 22.5 seconds), whereas the non-experience subjects' times did not stabilize until after 20 trials (mean time per subject across trials 21-50 = 32.4 seconds).

Frequency of errors were analyzed for each group. Between-group differences were negligible for all errors made. Direct reaches were the most common errors and were performed with equal frequency by each group (mean frequency per subject per block = 2.6 for both groups; U=7.0, ns). There was no significant decrease in performance of this error across blocks of trials (L=175, ns, for the experience group; L=176.5, ns, for the non-experience group; Figure 2.12). Tool contact errors were performed with equal infrequency by each group (mean frequency per subject per block = 0.2 for both groups; U=8.0, ns; Figure 2.13). Object insertions were also made with equal infrequency by each group (mean frequency per subject per block = 0.2 for both groups; U=7.5, ns; Figure 2.14). The non-experience group made incomplete insertion errors more frequently than did the experience group, although the difference was not significant (mean frequency per subject per block = 1.1 for the non-experience group vs. 0.2 for the experience group; U=5.0, ns; Figure 2.15). Incomplete pushes were

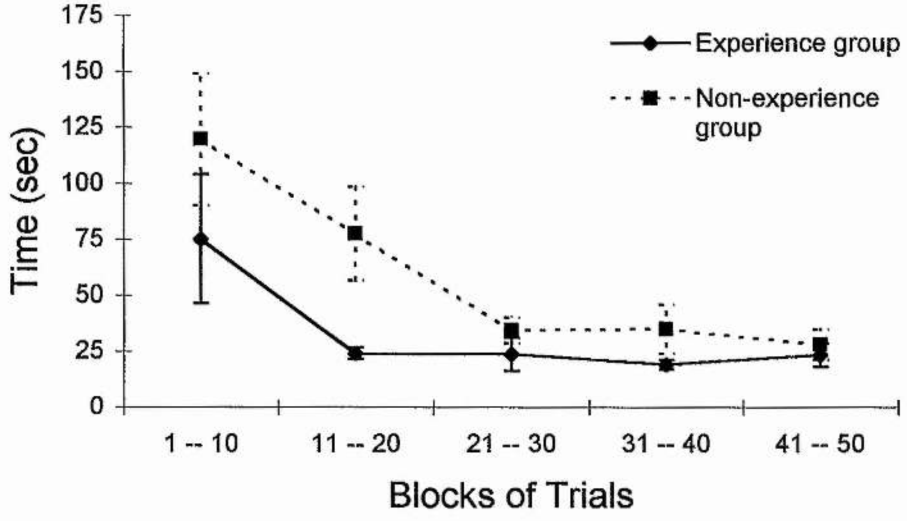


Figure 2.11. Mean trial completion time (±*SE*) per block averaged across subjects for each group.

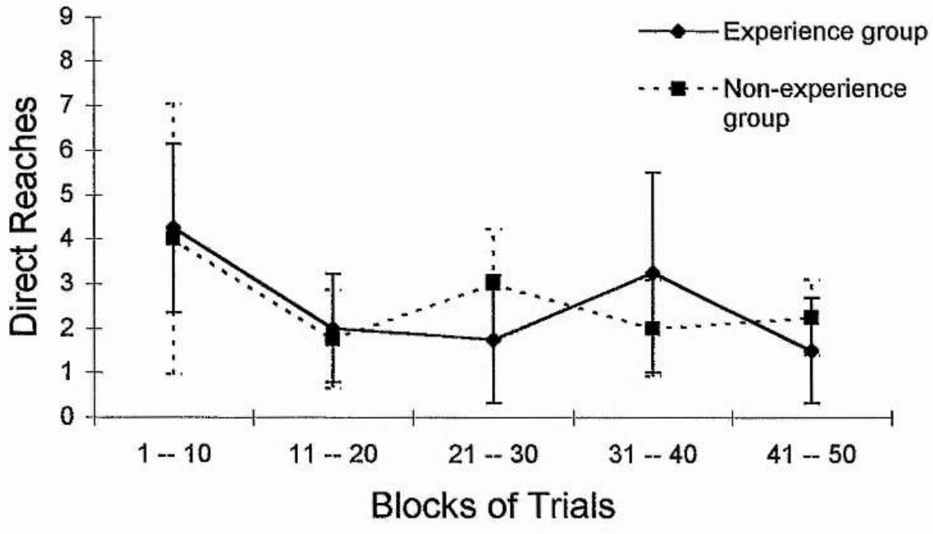


Figure 2.12. Total number of direct reaches (±*SE*) per block averaged across subjects for each group.

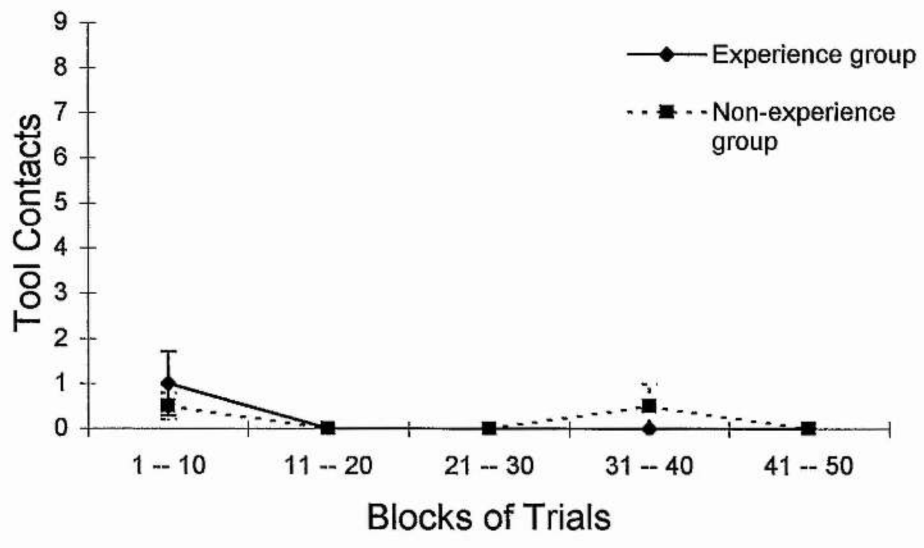


Figure 2.13. Total number of non-insertion tool contacts (±*SE*) per block averaged across subjects for each group.

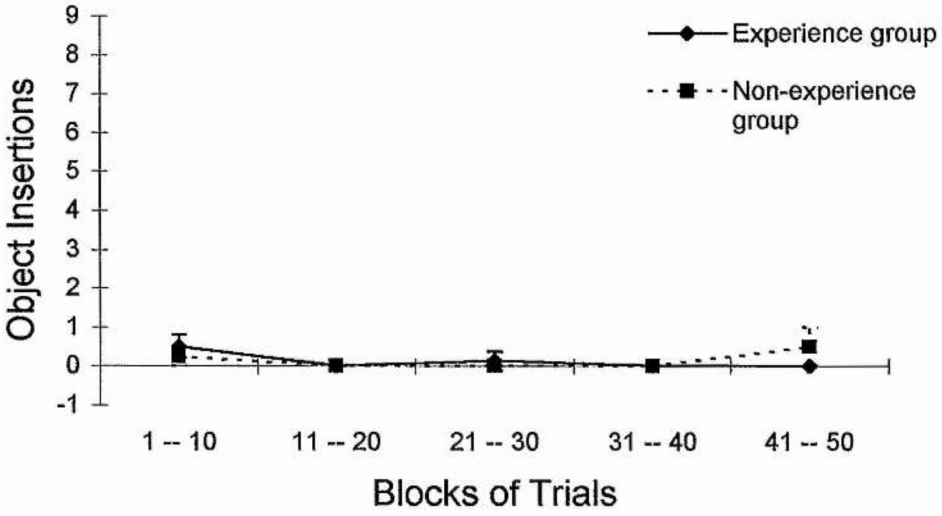


Figure 2.14. Total number of non-tool object insertions (±*SE*) per block averaged across subjects for each group.

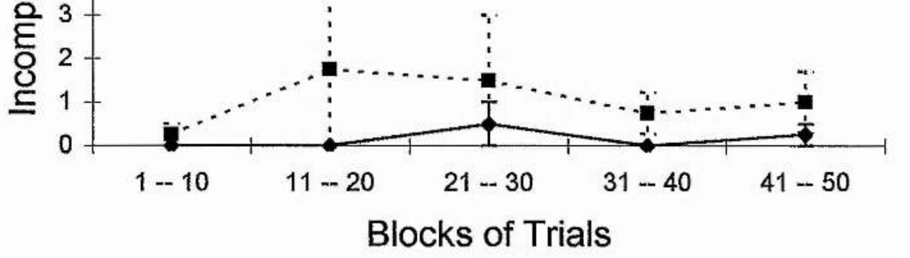


Figure 2.15. Total number of incomplete insertions (±*SE*) per block averaged across subjects for each group.

performed as frequently as direct reaches by the experience group and less frequently by the non-experience group, but the difference was not significant (mean frequency per subject per block = 2.6 for the experience group vs. 1.5 for the non-experience group; U=6.0, ns; Figure 2.16).

Finally, *reward loss* (losing the reward to a conspecific after dislodging it from the tube), *reward acquisition* (securing the reward after dislodging it), and *use of a strategy to secure the reward* were examined for between-group differences. There was no significant difference in frequency of reward loss (mean frequency per subject per block = 4.5 for the experience group vs. 5.1 for the non-experience group; U=4.0, ns), however the non-experience group significantly decreased their performance of this behavior across blocks of trials whereas the experience group did not (L=198.5, p<.05, for the non-experience group; L=191.5, ns, for the experience group; Figure 2.17). No significant difference between the groups was found for the mean trial at which subjects first acquired a reward after dislodging it (mean trial per subject = 5.0 for the experience group vs. 6.75 for the non-experience group; U=6.5, ns). Nor was any significant difference found for the mean trial at which subjects first used a strategy to secure their reward (mean trial per subject = 3.5 for the experience group vs. 4.75 for the non-experience group; U=5.0, ns).

Further information on the nature of reward loss comes from the qualitative notes. Losing the reward to a conspecific was a common problem for subjects. At first, subjects typically solved the task with their body positioned at the end of the tube into which they inserted the rod. The reward would fall out of the opposite end of the tube where a cagemate often sat waiting for it, sometimes with their hand inserted in the tube. This made it very difficult for the subject working on the task to get to the reward. Eventually, subjects incorporated the use of different strategies to secure the rewards for themselves. These strategies included positioning their body halfway between the ends of the tube and inserting the rod with one hand, while holding the other hand at the opposite end of the tube to catch the reward (Figure 2.18). Another strategy consisted of following the reward's movement through the tube, usually with the free hand cupped underneath

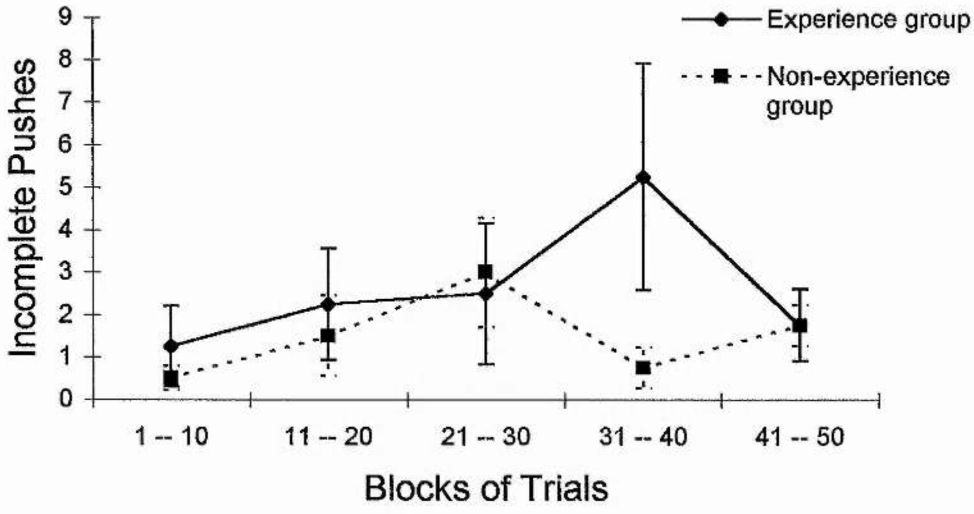


Figure 2.16. Total number of incomplete reward pushes (±*SE*) per block averaged across subjects for each group.

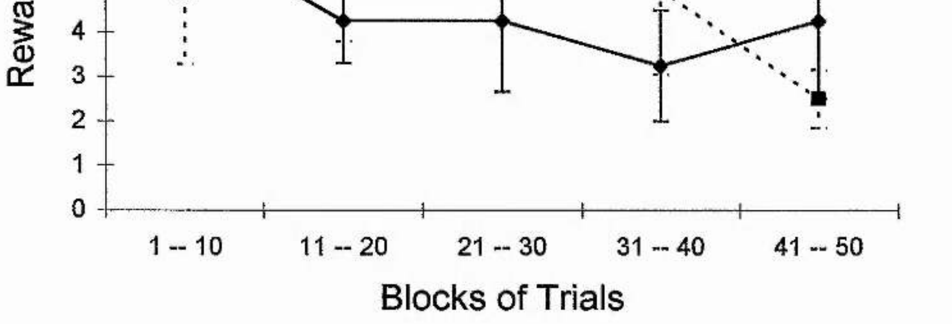


Figure 2.17. Total number of times reward was lost to a conspecific (±*SE*) per block averaged across subjects for each group.

Figure 2.18. Garth positions his body between the ends of the tube, inserting the rod with one hand and placing the other over the opposite end of the tube to catch the reward, thus preventing his cagemate from stealing it as Garth solves the task.

the tube, and catching the reward as it fell out of the tube. Following the reward's movement through the tube visually also appeared to be a beneficial strategy.

Discussion

I had hypothesized that the capuchins with manipulative experience would learn to use a tool to push the reward through the tube before subjects without such experience, and would continue to work more efficiently on the task by dislodging rewards more quickly and making fewer errors. The results from this experiment only partly supported these hypotheses. The experienced capuchins did not learn to push the rod through the tube any earlier than the non-experienced capuchins. Instead, the experienced subjects made more attempts to solve the task before their first solutions than did the non-experienced subjects; thus their first use of the rod as a tool to successfully dislodge the reward typically occurred after more trial and error experience, as well as more time with the task. Thereafter, the capuchins with manipulative experience generally dislodged rewards more quickly than did those without, although the non-experienced subjects improved their trial completion times across blocks of trials, eventually dislodging rewards as quickly as the experienced subjects. The capuchins with manipulative experience made no fewer errors while working on the task than did the non-experienced capuchins, and they lost rewards to conspecifics as frequently as did the non-experienced subjects. Subjects in both conditions became more careful to secure their rewards and not lose them to conspecifics as the trials progressed.

Despite this incomplete support for the original hypotheses, manipulative experience with the task objects did seem to have some effect on the capuchins' tool-using behavior. Most noticeably, capuchins with manipulative experience made more solution attempts before their first solutions and (after having completed the first solution) dislodged rewards from the tube more quickly than capuchins without experience. During the manipulative sessions that occurred after the first test trial, the experienced capuchins increased their frequency of rod manipulations in combination with the tube, including tool insertions, and this experience would explain their faster completion times, especially their sudden decrease to the fastest time in the second block of trials.

It must be kept in mind, however, that the actual type and amount of manipulative experience differed between subjects. In general, the younger monkeys spent more time manipulating the objects than did the older ones. Despite Zephyr's low level of manipulation, it is interesting to note that both he and Java increased their frequency of rod manipulations in combination with the tube after Garth's first solution instead of after their own first solutions (Garth's first solution occurring before either Zephyr's or Java's). This suggests that their object manipulations may have been influenced by having observed Garth's manipulations with the tube during test and manipulative sessions. If this was the case, Zephyr's quick and effective performance on the task may also have been influenced by observing other subjects during testing. Therefore, the necessary experience with the task objects to enhance task performance may include not only physical manipulation of the objects, but also visual experience with the objects or with others manipulating them. Consistent with the published literature (see Visalberghi & Fragaszy, 1990, and Whiten & Ham, 1992, for reviews), though, there was no evidence for imitation in this experiment; all subjects in both groups made attempts to solve the task by manipulating task objects before their first solution. However, Zephyr and Java's sudden increase in rod manipulations in contact with the tube after Garth's first solution suggest the possibility of stimulus enhancement.

Because the capuchins could observe other subjects manipulating the task objects and working on test trials, it is important to recognize this potential for social learning. Although there is a lack of evidence for imitation among capuchins, they do seem capable of other forms of social learning, such as stimulus enhancement and social facilitation (Tomasello & Call, 1997; Visalberghi & Fragaszy, 1990; Whiten & Ham, 1992). It is possible that social effects could confound the intended experimental manipulation, object manipulation experience, by additionally enhancing subjects' performance on the task. Social influences may also reduce the effective sample size of each group if those subjects who observed the first subject's solutions learned how to solve the task more quickly as a result of their observations. The problem is that if, by chance, an individual in one group learns how to solve the task earlier than individuals in the other group, and can serve in some way as a "demonstrator" to the others, then this group as a whole may tend to solve the task more quickly. However, if one group would be expected to perform better on the task as a result of having a better "demonstrator", then it would not in fact have been the experience group in this experiment. The first subject to solve the task in the non-experience group, Creepshow, performed the quickest, most efficient solution of all subjects in both groups and continued to perform similarly on subsequent trials. On the assumption of non-independent subjects, non-experience group subjects would be expected to perform better on the task if they had learned how to solve it as a result of watching Creepshow. As the data demonstrate, this was not the case, which suggests that the treatment of individuals as independent may in fact not be statistically invalid for these capuchins.

In sum, the results of this experiment suggest that experience with objects enhances capuchins' performance on a tool-using task. A possible explanation for this is that the manipulative sessions provided an opportunity to learn more about the *affordances* (Gibson, 1977) of the objects as tools, that is, the range of actions that can be performed with them, and the specific relation between the tools and the task. This more focused experience, which seemed to occur after having solved the task for the first time, may help the subjects learn the most efficient way to use the tool to solve the task. However, this is only one possible interpretation; this issue will be explored in more detail in Chapter 6. Because attempts before first solution, and subsequent trial completion times, were the only measures influenced by experience on this task, it would be interesting to examine if the effects of experience increase when a more complex task is presented. Perhaps a task in which the types of errors made have a greater effect on the outcome of the task. The next chapter will introduce such an experiment.

Chapter 3

Experiment 2: Tool modification task I. Tool combination

In order to examine the effects of object manipulation experience on capuchins' performance on a more complex task, in which the potential errors have greater effect on the outcome, this experiment introduced a variation of the basic tube task (Experiment 1, Chapter 2), requiring modification of an object in order to use it as a tool. In the first experiment, the effects of manipulative experience on learning how to perform a novel tool behavior were explored by introducing a simple task involving the use of a rod as a tool to push a reward out of a tube. Capuchins with manipulative experience did not first learn to push the rod through the tube to dislodge the reward any earlier than capuchins without experience; however they did make more attempts to solve the task before their first solution, as well as dislodge rewards more quickly on subsequent trials. It was not clear why the experienced capuchins made as many errors on the task as did the non-experienced capuchins; however, it is possible that the errors scored in this task did not have enough influence on the outcome of the task to elicit a significant difference between the conditions. For example, reaching for the reward manually or failing to insert the rod far enough into the tube, although delaying solution slightly, did not significantly hinder reward acquisition. An error which has to be undone or which blocks reward acquisition might have a greater influence on the outcome of the task because an additional series of behaviors have to be performed to correct the error before reattempting to solve the task, significantly delaying solution. Therefore, a task with the potential for errors that have a greater influence on the outcome may help to further explore the effects of experience on capuchins' tool-using performance.

The current experiment introduced a more complex version of the tube task used in the first experiment. The apparatus was the same; with solution achieved by using a tool to dislodge the reward from the center of the clear tube. However, the objects provided for use as tools were pipes that were too short to solve the task and therefore had to be combined, either by connecting them together or by using them sequentially, to create a tool with sufficient length to push the reward out of the tube (see Figure 3.1).

As in the previous experiment, the variable of object experience was manipulated by providing the experience group with opportunities to explore the materials used in the task. The non-experience group was not given the same opportunity. The same monkeys were used as in Experiment 1, so they should have been familiar with the basic procedure. A set of pre-defined, task-oriented behaviors were recorded during the sessions, similar to those recorded in the previous experiment and incorporating behaviors recorded by Visalberghi and Trinca (1989) using the same task. The errors scored for this experiment were different from those scored in the first experiment, being specific to the use and combination of the shorter pipes. In contrast to the first experiment, there was considerable scope for errors that significantly affected the task outcome. For example, blocking the reward from both sides of the tube by inserting pipes individually on either side of the tube should delay reward acquisition more so than failing to push a rod far enough through the tube after its insertion (the incomplete push error from the first experiment). This is because the first error requires a second action to be performed to correct it (removing the pipe that is blocking the reward) before reattempting to solve the task, whereas the latter simply requires another attempt (another push).

As before, it was hypothesized that manipulative experience with the task materials would enhance the capuchins' performance on this task. Specifically, experienced capuchins were expected to dislodge rewards more quickly than non-experienced capuchins. Additionally, because this task involved combinatorial tool modification (connecting the pipes together or using them in combination) and the consequences for making errors were greater than in the previous experiment, it was expected that the experienced capuchins would also work more efficiently than the non-experienced capuchins, by making fewer errors on the task.

Figure 3.1. Creepshow creates a tool with sufficient length to dislodge the reward by inserting three pipes into the same end of the tube.

Method

Subjects

The subjects were the same eight capuchins already used in Experiment 1. The experience and non-experience groups remained the same. Subject's housing, diet, and provision of enrichment objects also remained the same as in Experiment 1.

Materials

The tube apparatus and frames were the same as those used in Experiment 1. The objects provided for use as tools in this experiment were 11 plastic pipes (7.5 cm in length and 1.3 cm in diameter; see Figure 3.2). The pipes used in this experiment had been created by sawing into smaller pieces the pipes used in the previous experiment. Three of the pipes had plastic pipe connectors on one end, to allow the pipes to be connected together, and nothing on the other end, to allow them to fit into a connector piece. Three of the pipes had a cap on one end, preventing that end of the pipe from being connected to another pipe, and nothing on the other end. The caps on the pipes were from the previous experiment in which they had been used to prevent the reward from becoming lodged inside the pipe. Three of the pipes had nothing on either end of them. One pipe had a cap on one end from the previous experiment, and a connector on the other end. And one pipe was actually a connector piece (4 cm in length) instead of a pipe; therefore, a pipe could be connected to either end of it, or it could be used to connect two pipes with free ends. In sum, four pipes had connectors on one end, six pipes did not have connectors on either end, and one pipe was a connector piece. The pipes could be connected to one another by fitting them together at the connectors (or using the unattached connector piece), or they could be used individually but in combination with one another by inserting them into the tube one behind another.

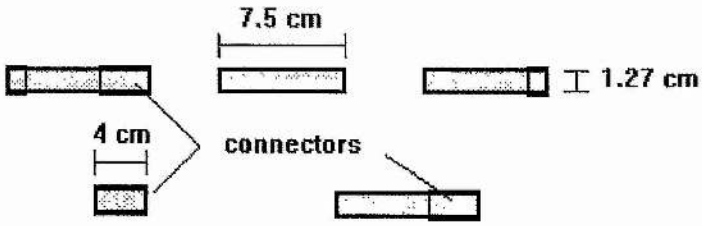


Figure 3.2. A selection of the pipes provided for use as tools.

Procedure

Manipulative sessions

The experience group subjects received a series of four 30-minute manipulative sessions before each of their first two test sessions (see Table 3.1). No additional manipulative sessions were given before their third test sessions because each subject had already completed 80% of their trials. During manipulative sessions, the apparatus was mounted inside the cage, but no reward was provided. All 11 pipes were placed on the cage floor, and they were resupplied if subjects threw them out of the cage during the session. The enrichment objects in the cage (see Experiment 1, Chapter 2) were also available, but they were not specifically supplied for this experiment. A set of pre-defined behaviors (Table 3.2) were recorded during the session. Because of the difficulty with keeping track of 11 small pipes scattered throughout the cage in addition to recording activities taking place at the tube apparatus, *tool manipulation* (manual manipulation of the pipes) was not recorded for this experiment. However, qualitative notes indicated the presence of tool manipulation during the sessions. All animals in the social group had access to the provided materials during the manipulative sessions; subjects were not separated from their group. The non-experience group did not receive any manipulative sessions; instead, they were tested on a continuous testing schedule until each subject had completed 25 trials (see Table 3.3).

Test sessions

Test sessions were conducted with both groups until subjects completed 25 trials each. At the beginning of each test session, the apparatus was mounted inside the cage and baited as in Experiment 1. All 11 pipes were provided on the cage floor or shelf next to the apparatus. Pipes were resupplied during the trial if subjects threw them out of the cage. The enrichment objects were also available, although not specifically provided for the experiment. A trial began when the lab coat used for baiting the tube out of view was removed from the apparatus. A trial ended when either the subject dislodged the reward by pushing the pipes through the tube, or after a full minute elapsed without any tool contact with the tube by

Table 3.1

Schedule of Manipulative and Test Sessions for Experience Group Subjects

Garth	Java[a]	Zephyr[a]	Jesse
manipulative 1	manipulative 1	manipulative 1	manipulative 1
manipulative 2	manipulative 2	manipulative 2	manipulative 2
manipulative 3	manipulative 3	manipulative 3	manipulative 3
manipulative 4	manipulative 4	manipulative 4	manipulative 4
test 1: trials 1-10	**test 1: trials 1-7**	**test 1: trials 1-7**	**test 1: trials 1-4**
manipulative 5	manipulative 5	manipulative 5	manipulative 5
manipulative 6	manipulative 6	manipulative 6	manipulative 6
manipulative 7	manipulative 7	manipulative 7	manipulative 7
manipulative 8	manipulative 8	manipulative 8	manipulative 8
test 2: trials 11-20	**test 2: trials 8-20**	**test 2: trials 8-19**	**test 2: trials 5-20**
test 3: trials 21-25	**test 3: trials 21-25**	**test 3: trials 20-25**	**test 3: trials 21-25**

[a] Java and Zephyr worked together on Java's trials 16, 18, and 19 (Zephyr's trials 22, 23, and 24).

Table 3.2

Operational Definitions of Behaviors Recorded During Manipulative Sessions

Behavior:	Operational Definition:
Manipulation	Manual handling of an object.
Manual contact	Touching the tube with one or more hands.
Tool contact	Making contact with the tube by means of a pipe.
Tool insertion	Putting a pipe into the tube.
Tool removal	Taking a pipe out of the tube, not including pipes that are inserted and removed as one action.
Tool connection	Connection of two or more pipes, creating a longer tool.
Bout	A behavior performed several times in succession without break or interpolation of a behavior of another type.

Table 3.3

Schedule of Test Sessions for Non-Experience Group Subjects

Creepshow[a,e]	Lee[b]	Iko[c,e]	Squeak[d,e]
test 1: trials 1-4	test 1: trials 1-8	test 1: trial 1	test 1: trials 1-2
test 2: trials 5-7	test 2: trial 9	test 2: trials 2-8	test 2: trials 3-4
test 3: trials 8-11	test 3: trials 10-25	test 3: trials 9-11	test 3: trial 5
test 4: trial 12		test 4: trials 12-13	test 4: trials 6-14
test 5: trials 13-25		test 5: trial 14	test 5: trials 15-25
		test 6: trials 15-25	

[a] Creepshow's trials 2, 4, and 11 were unsolved. [b] Lee's trials 8 and 12 were unsolved.
[c] Iko's trial 14 was unsolved. [d] Squeak's trials 1, 2, 5, 22, and 25 were unsolved.
[e] Creepshow and Squeak worked together on Creepshow's trials 2 and 4 (Squeak's trials 1 and 2). Creepshow and Iko worked together on Creepshow's trial 11 (Iko's trial 14).

the subject or any other animal in the test cage, since interest by other animals may have stimulated interest by the subject, and no further tool manipulation with the tube began at the onset of the next minute. This criterion for ending an incomplete trial was decided upon in the interest of time because some of the subjects were becoming increasingly difficult to work with. Test sessions had no fixed duration, but typically lasted between 60 and 240 minutes. The number of trials completed during each test session varied depending on the subject, the length of each trial, and social factors interfering with testing.

A set of pre-defined behaviors (Table 3.4) and trial completion times were recorded for each trial. Qualitative notes including such information as the order in which the pipes were inserted, the side of the tube into which pipes were inserted, which pipes fell out of the tube when other pipes or subjects' hands were inserted, when subjects left the apparatus or stopped working, and which pipes were not left in the tube after insertion provided supporting details.

Subjects were separated during testing such that at least one subject was in the test cage in addition to a few other animals from the social group to keep them company. Interference with the task by non-subject animals was taken into account when coding the data. Errors caused by another animal were not counted as an error for the subject working on that trial (for example, if a non-subject animal removed a pipe from the tube, typically scored as a removal error, the error would not be counted because it was not performed by the subject animal). However, due to the difficulty of separating animals that were not trained for separation, there were occasions when more than one subject was in the test cage during testing. It was not possible to prevent subjects from working on some of the trials together. These trials are denoted in Tables 3.1 and 3.3. Due to the difficulty of testing subjects during this experiment, these trials were not thrown out, nor were additional trials given in which the subjects were separated individually. Squeak and Java participated in the majority of these shared trials, and because they were the most difficult subjects to separate from their groups, it was not practical to attempt to separate them individually for further testing.

Table 3.4

Operational Definitions of Behaviors Recorded During Test Sessions

Behavior:	Operational Definition:
Tool insertion	Putting a pipe into the tube.
Success	Dislodgment of the reward after having inserted the pipes into the tube.
Tool removal	Taking a pipe out of the tube, not including pipes that are inserted and removed as one action.
Tool connection	Connection of two or more pipes, creating a longer tool.
Insertion error	A) Insertion of a pipe into the opposite side from which the previous pipe was inserted, when one or more pipes have already been inserted into one side of the tube and no pipes have been inserted into the opposite side.[a] B) Insertion of a pipe into the FFS[b] side of the tube, when one or more pipes have already been inserted into both sides of the tube.[c]
Removal error	A) Removal of a pipe from the CTS side of the tube.[d] B) Removal of a pipe from the tube and subsequent reinsertion of it into the same side of the tube from which it was removed.[e] C) Removal of a pipe from the CTS side of the tube and subsequent reinsertion of it into the FFS side of the tube.[f]

[a] For example, if the first pipe was inserted into the left side of the tube, then inserting the next pipe into the right side of the tube would be an error because it does not bring the problem any closer to solution, and blocks the reward from both sides of the tube. Similarly, if two pipes have been inserted into the left side of the tube, then inserting the third pipe into the right side of the tube would be an error because the third pipe would have been sufficient to push the reward out of the tube if inserted on the left side, but when inserted on the right side, it blocks the reward. [b] *FFS* (*farthest from solution*) = the side of the tube with fewer inserted pipes, therefore being farther from solution than the other side when considering the next pipe insertion. *CTS* (*closest to solution*) = the side of the tube with more inserted pipes, therefore being closer to solution when considering the next insertion. [c] If two pipes have already been inserted into the left side of the tube, and one pipe has already been inserted into the right side, then the left side of the tube is CTS and inserting the next pipe into the left side would lead to solution, whereas inserting the next pipe into the right side, the FFS side, would be an error. [d] If two pipes have been inserted into the right side of the tube and no pipes have been inserted into the left side, then removing a pipe from the right side would be an error because it hinders solution. Similarly, if three pipes had been inserted into the right side of the tube and one pipe had been inserted into the left side of the tube, then removing a pipe from the right side of the tube would be an error. [e] If a pipe had been inserted on the left side of the tube, removing that pipe and then reinserting it into the same side of the tube would be an error because it delays solution by repeating an insertion which had already been performed. [f] If three pipes had already been inserted into the left side of the tube, and one pipe had been inserted into the right side of the tube (blocking the reward), then removing a pipe from the left side (CTS side) of the tube and reinserting it into the right side (FFS side) of the tube would be an error because it would hinder solution by further blocking the reward.

Analysis

The same analyses, the Mann-Whitney U test and the Page Test for Ordered Alternatives, were used as in Experiment 1 to examine between-group differences and performance trends across blocks of trials. Blocks of trials consisted of 5 trials each for purposes of comparison with the next experiment in the series (Chapter 4) and with Visalberghi and Trinca's (1989) experiment using the same task.

Results

Manipulative sessions

Subjects showed consistent interest in the pipes and the tube throughout the manipulative sessions. Garth, Java, and Jesse manipulated the objects most frequently, whereas Zephyr rarely contacted the materials (Figure 3.3). The majority of Garth, Java, and Jesse's manipulations were tool insertions (32.9%, n=61; 39.6%, n=67; and 44.5%, n=69, of total manipulations for each subject, respectively) and manual contacts with the tube (27.6%, n=51; 34.4%, n=58; and 25.8%, n=40, of total manipulations for each subject, respectively; Figure 3.4). However, they were also observed to spend a lot of time engaged in tool manipulation during the sessions. Although it was not possible to take quantitative data on subjects' pipe manipulations, the qualitative notes suggested that tool manipulation was among the most frequent of manipulations, especially for Garth. Because subjects made tool insertions during the manipulative sessions, it was expected that their experience would enhance their performance on the task. Zephyr's performance was not expected to be enhanced by the manipulative sessions since he only manipulated the objects twice.

Garth was the only subject observed to connect the pipes together and pull them apart repeatedly during the sessions. Many of Garth's tool connections may have been missed due to the difficulty with recording his tool manipulations while recording all other activities taking place at the apparatus, but the data show that at least 30.8% (n=57) of his total manipulations were tool connections. Connecting two or more pipes together was a complex task. The appropriate ends of each pipe had to be lined up to

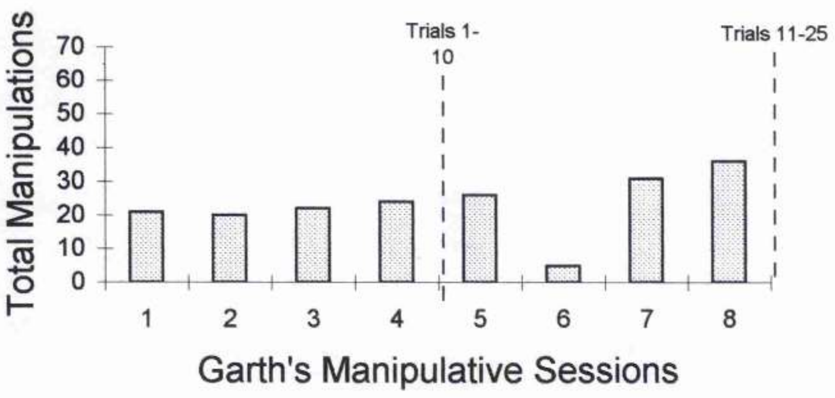


Figure 3.3a. Total number of bouts of object manipulation for each of Garth's manipulative sessions. Note that dotted lines show when test trials were completed.

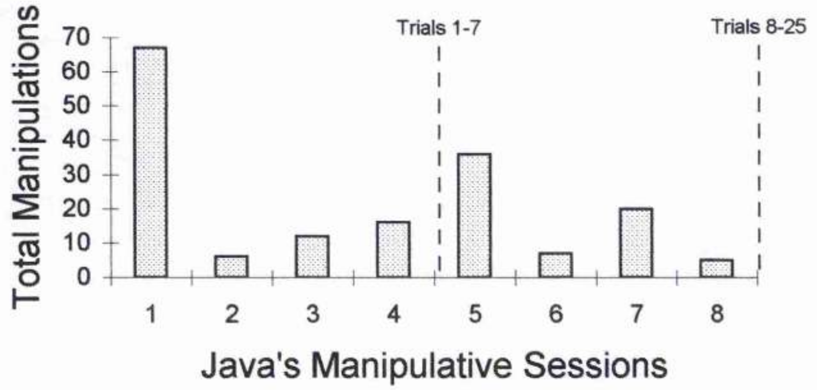


Figure 3.3b. Total number of bouts of object manipulation for each of Java's manipulative sessions.

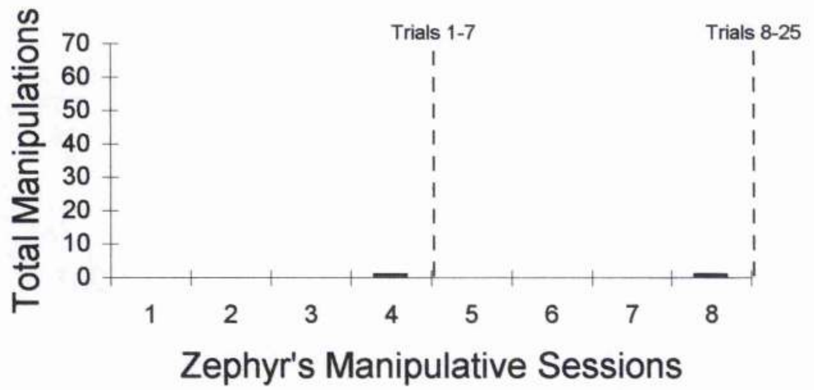


Figure 3.3c. Total number of bouts of object manipulation for each of Zephyr's manipulative sessions.

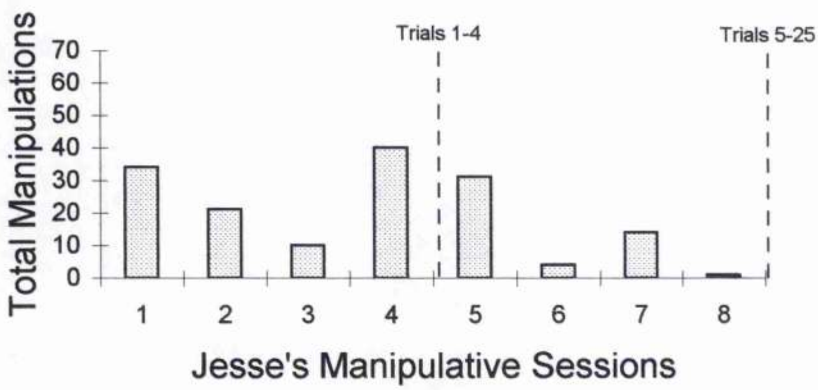


Figure 3.3d. Total number of bouts of object manipulation for each of Jesse's manipulative sessions.

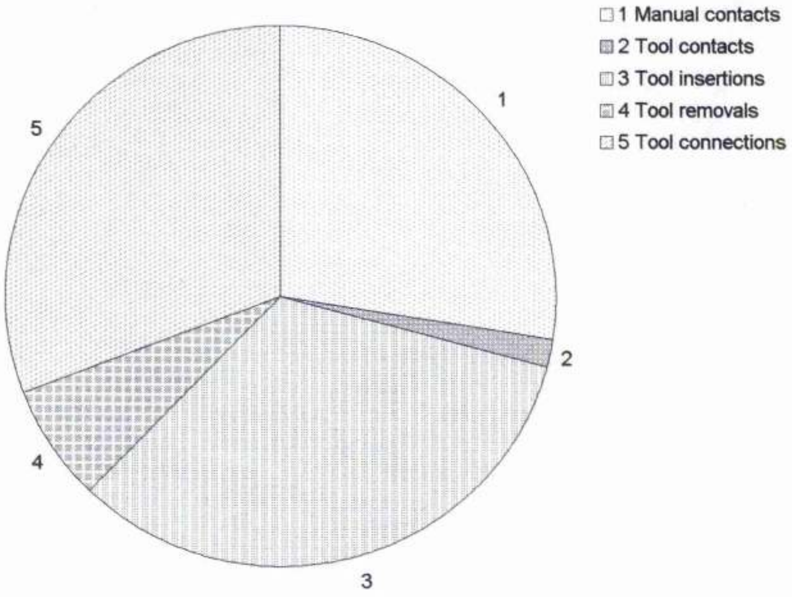


Figure 3.4a. Total object manipulations performed by Garth during manipulative sessions.

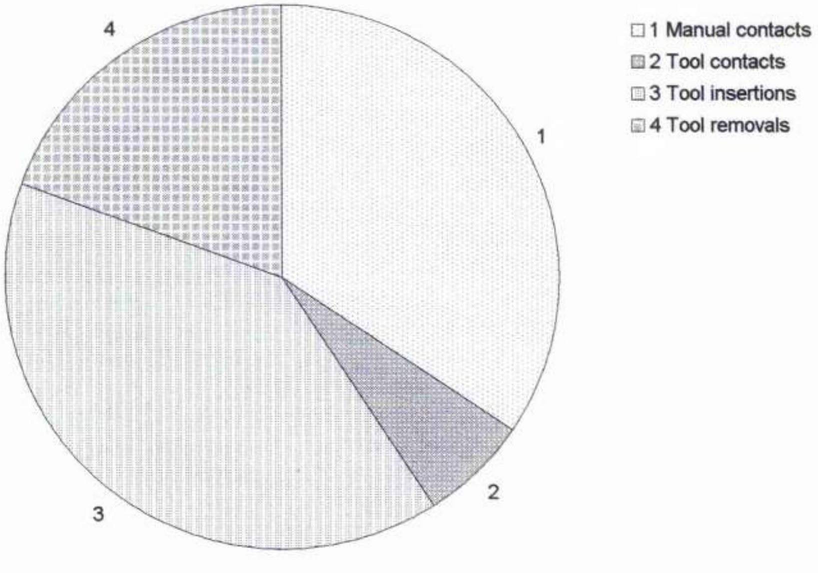


Figure 3.4b. Total object manipulations performed by Java during manipulative sessions.

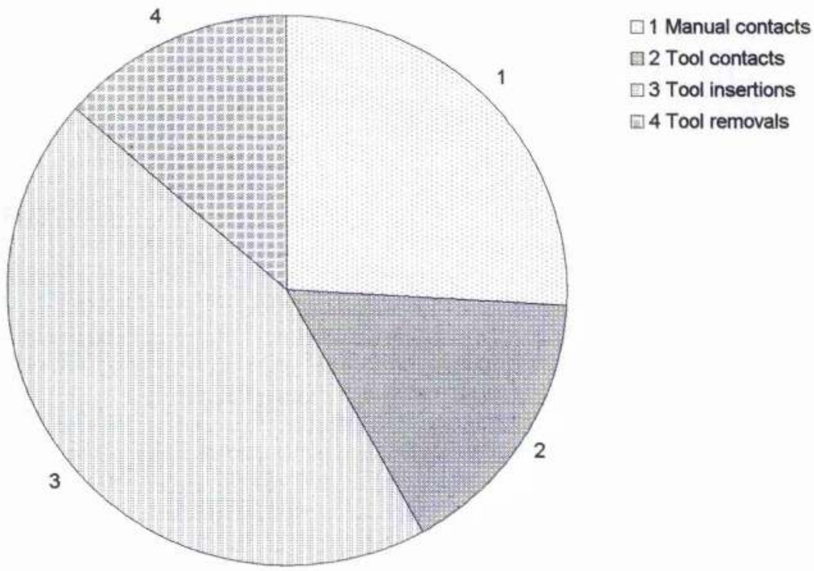


Figure 3.4c. Total object manipulations performed by Jesse during manipulative sessions.

fit together. Because some pipes had connectors on them and others did not, it was necessary to fit together the connector end of one pipe with the plain end of another pipe. Garth did not seem to have much difficulty connecting pipes. The majority of his tool connections consisted of two pipes fitted together, although Garth also connected three pipes on a few occasions. Because Garth connected tools together during the manipulative sessions, it was expected that he would connect them together during testing to create longer tools to solve the task with. It was not expected that any of the other subjects would do this.

Test sessions

The non-experience group subjects seemed to have more difficulty solving this task than did the experience group subjects: they were less cooperative during testing, consequently needing more sessions to complete 25 trials, and a number of their trials ended (because they had stopped working on the task for a full minute) before they dislodged the reward. *Unsolved trials* were not used in the analysis of trial completion times; however, they were used for all other analyses. These trials were: trials 8 and 12 for Lee, trials 2, 4, and 11 for Creepshow, trials 1, 2, 5, 22, and 25 for Squeak, and trial 14 for Iko. It is likely that Squeak had the greatest number of unsolved trials because he received threats from dominant cagemates while working on the task and therefore became stressed throughout the duration of this experiment. Two of Squeak's trials (1 and 2) were shared with Creepshow, so Squeak may have influenced Creepshow's emotional state, causing him to leave the trials unsolved as well. The non-experience group subjects left a significantly greater number of trials unsolved than did the experience group subjects, which dislodged the reward on every trial (mean number of unsolved trials per subject = 2.8 for the non-experience group vs. 0.0 for the experience group; Mann-Whitney U test, U=0.0, p<.05; Figure 3.5).

An interesting and unexpected solution technique was used to dislodge rewards on a number of trials by most of the subjects. The technique involved using force to project one short pipe through the tube that would push the reward out, occasionally projecting it from the tube. Because

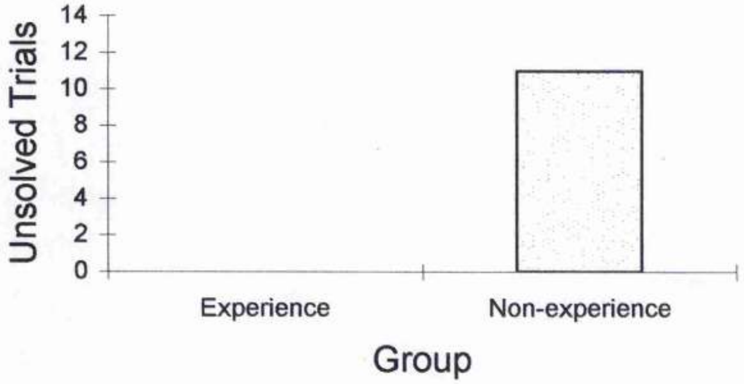


Figure 3.5. Total number of trials ended without dislodging a reward for each group.

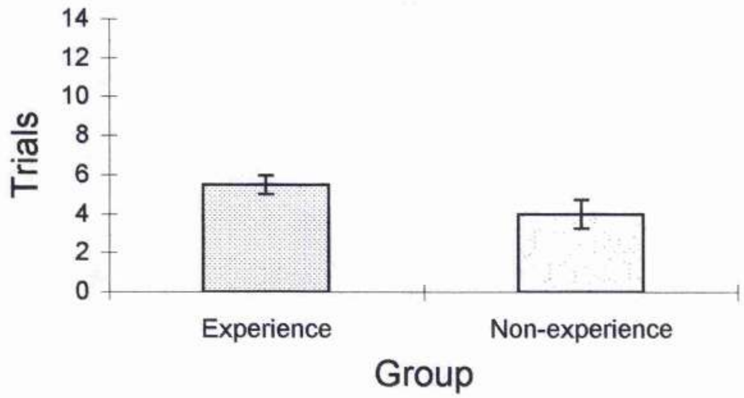


Figure 3.6. Total number of one-tool solution trials (±*SE*) averaged across subjects for each group.

the task was designed such that the insertion of at least two or three pipes would be necessary to push the reward out of the tube when inserted one behind the other, or when connected together and used as a longer tool, this technique of projecting one pipe through the tube to dislodge the reward (*one-tool solution*) had not been planned for. The groups were compared to see if there was any difference in their frequency of one-tool solutions, however the difference was not significant (mean frequency per subject per block = 1.1 for the experience group vs. 0.8 for the non-experience group; U=5.5, ns; Figure 3.6).

Next, a comparison of trial completion times revealed no significant difference between the experience group and non-experience group subjects. Although the experience group dislodged rewards more quickly than the non-experience group, the difference was not significant (mean time per subject per trial = 58.2 seconds for the experience group vs. 81.1 seconds for the non-experience group; U=4.0, ns; Figure 3.7). Additionally, the experience group significantly increased their completion times across blocks of trials (Page Test for Ordered Alternatives, L=197, p=.05).

Frequencies of errors were then analyzed for differences between the groups. Because on a number of trials subjects dislodged rewards by projecting one pipe through the tube, insertion errors in which the second pipe was inserted into the opposite side of the tube from the first pipe but dislodged the reward anyway were counted as one-tool solutions instead of errors. Although it was an error to insert the second pipe on the opposite side of the tube, it made more sense to count it as a one-tool solution when it was inserted with sufficient force to solve the task. Insertion errors were performed more frequently by the experience group than by the non-experience group, however the difference was not significant (mean frequency per subject per block = 5.0 for the experience group vs. 3.9 for the non-experience group; U=7.0, ns; Figure 3.8). The non-experience group continued to make this error consistently across blocks of trials, whereas the experience group significantly increased their performance of this error across blocks of trials (L=207, p<.01). Removal errors were performed less frequently by the experience group than by the non-experience group, however the difference was not statistically significant (mean frequency per

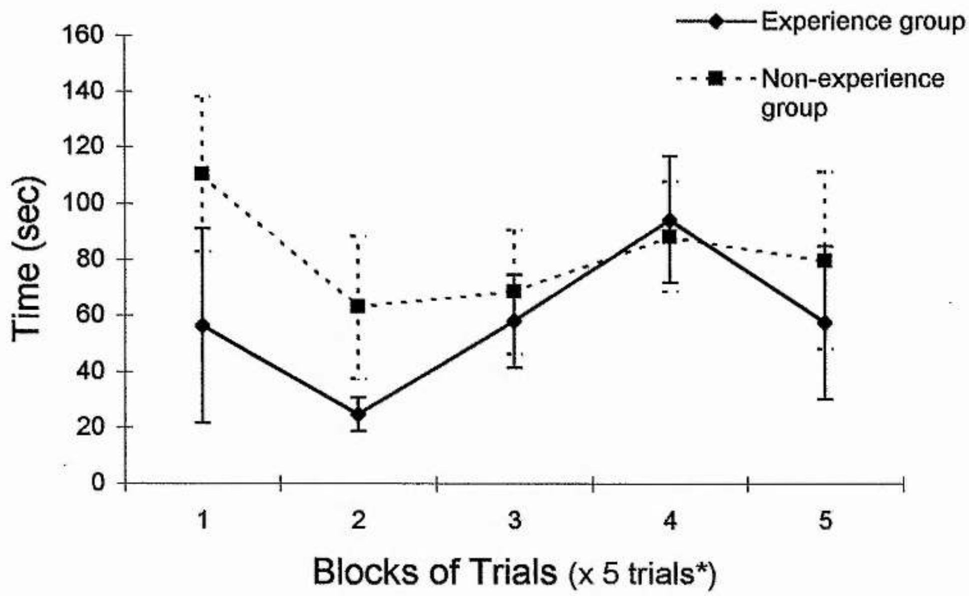


Figure 3.7. Mean trial completion time (±*SE*) per block averaged across subjects for each group.

*Note that blocks consist of 5 trials for each subject except for the following: block 1 consists of 3 trials for Creepshow and 2 trials for Squeak, block 2 consists of 4 trials for Lee, block 3 consists of 4 trials for Lee, Iko, and Creepshow, and block 5 consists of 3 trials for Squeak.

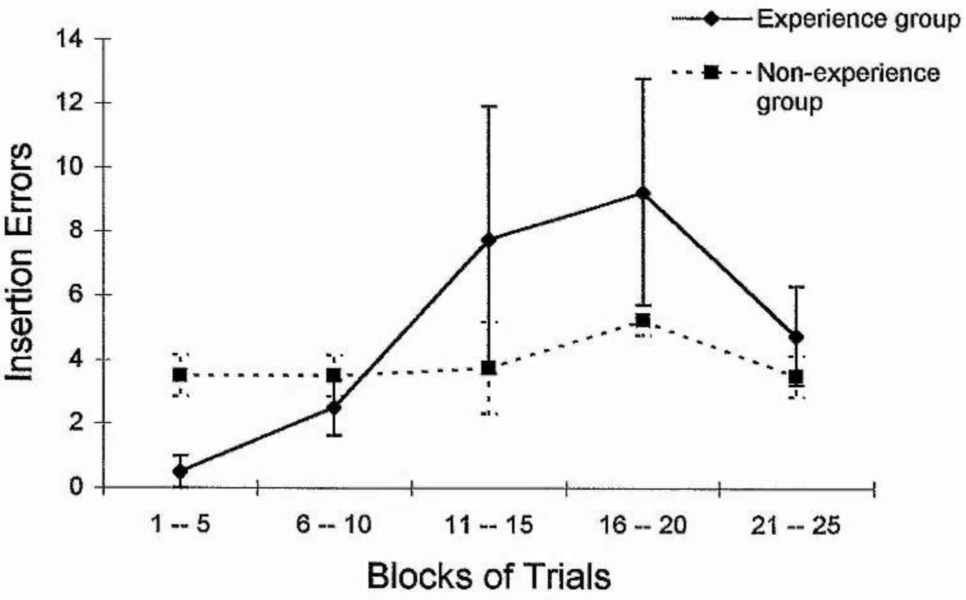


Figure 3.8. Total number of insertion errors (±*SE*) per block averaged across subjects for each group.

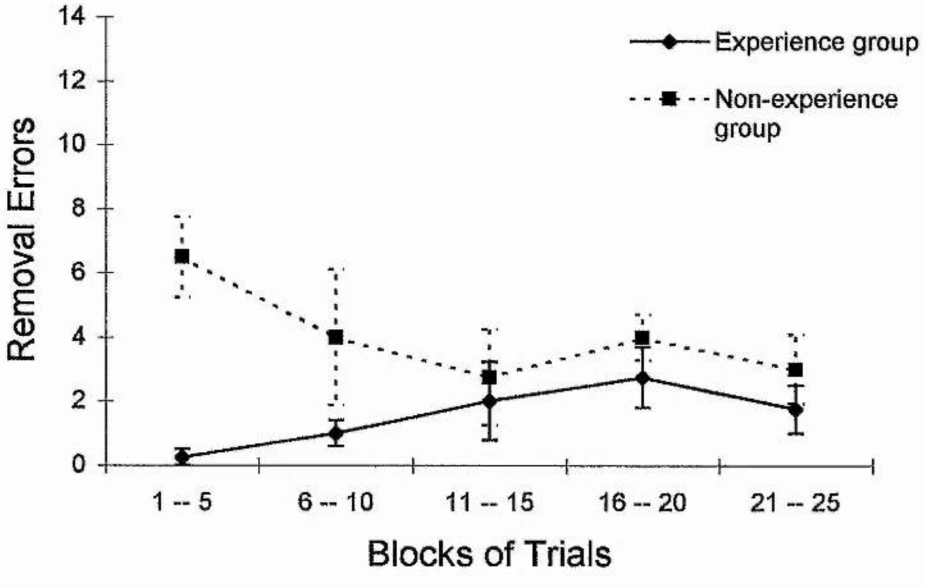


Figure 3.9. Total number of removal errors (±*SE*) per block averaged across subjects for each group.

subject per block = 1.6 for the experience group vs. 4.1 for the non-experience group; *U*=2.0, *p*=.083; Figure 3.9). The experience group increased their frequency of this error across blocks of trials, whereas the non-experience group decreased their frequency of this error across blocks of trials, however, neither trend was significant (*L*=194.5, ns, for the experience group; *L*=195, ns, for the non-experience group).

Considering the frequency of errors made on this task, it is not surprising to note that tool connections were infrequent. Although subjects were never actually observed to connect the pipes together during the test sessions, there were seven trials during which the use of connected pipes was observed. Twice, Java inserted two pipes that were connected together into the tube (trials 14 and 23). He also manipulated a pair of connected pipes in contact with the tube during one of Zephyr's trials (trial 20). Jesse inserted a pair of connected pipes into the tube on two trials as well (trials 21 and 22). Garth attempted to insert a connected pipe tool into the tube on trial 21, however the tool broke apart when the first part was inserted and he then inserted the second pipe into the other side of the tube. He did successfully insert one pair of connected pipes on trial 25. Because these tool connections were never observed, and because Java and Jesse were never observed to connect tools during the manipulative sessions, it is most likely that either Garth had connected the pipes prior to their use on Java and Jesse's trials, or that the pipes became connected when they were pushed together inside the tube. Although Garth was not in the test cage during Java and Jesse's trials, it was not uncommon for some of the pipes to be tossed into the adjoining cage by subjects or their cagemates, or for Garth to reach into the test cage and remove pipes. Therefore, it is possible that he connected the pipes and tossed them back into the test cage, or that subjects in the test cage reached over and removed connected pipes from the non-test cage.

Finally, the frequency of *stopping work mid-trial* was analyzed for each group. This behavior is different from leaving trials unsolved because it only involves taking a break from working on the task, after which the subject may have returned and continued working. Therefore, this behavior occurred both during trials in which subjects dislodged the reward, as well as during trials in which they did not. The non-experience group stopped working mid-trial more frequently than did the experience group, however the difference was not significant (mean frequency per subject per block = 3.6 for the non-experience group vs. 1.1 for the experience group; U=2.5, ns; Figure 3.10).

Discussion

My initial hypothesis for this experiment was that the capuchins who had manipulative experience with the materials used in the task would dislodge the rewards more quickly and make fewer errors than the capuchins without such experience. The results did not support this hypothesis. There were no significant differences in performance between the two groups of capuchins across measures of trial completion time, error frequency, or stopping work mid-trial. The only significant difference between the groups was the frequency of unsolved trials. For some reason the non-experienced capuchins left 11 trials unsolved, whereas the experienced capuchins did not leave any trials unsolved. As far as performance trends, the subjects did differ with respect to the fact that the experienced subjects significantly *increased* their trial completion times and frequency of insertion errors across blocks of trials, whereas the non-experienced subjects did not. It is not clear why the experienced capuchins' performance deteriorated across blocks of trials.

Manipulative experience with the objects, therefore, did not have a positive effect on the capuchins' performance. Although three of the experienced subjects manipulated the pipes and the tube during manipulative sessions, particularly performing tool insertions, they did not benefit from this experience with the task. Perhaps the absence of a reward during the manipulative sessions prevented subjects from learning the benefits of inserting pipes in sequence into the same end of the tube. If there was nothing to push out of the tube, and the pipes could be inserted without combining them, then there was no reason for subjects to connect the pipes or to insert them one after another. However, on many occasions, subjects did insert pipes into the tube in sequence during the manipulative sessions. Therefore, it is unclear why they did not learn about the function of the combined objects as a more efficient tool.

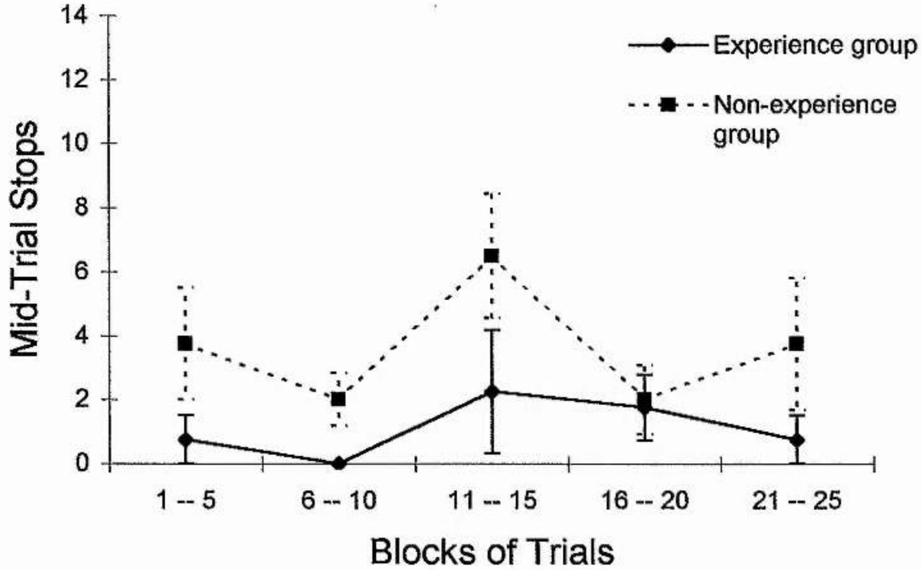


Figure 3.10. Total frequency of stopping work mid-trial (±*SE*) per block averaged across subjects for each group.

It is also unclear why Garth did not use his skill at connecting pipes, acquired during the manipulative sessions, to create longer tools with which he could have solved the task more efficiently during testing. Perhaps he did not relate the longer pipes, created by connecting smaller pipes together, to the problem presented by the task because he had performed the tool connections at a perch away from the apparatus and did not subsequently insert the longer tools into the tube.

A factor that may have interfered with this experiment was that subjects developed a strategy to project one short pipe through the tube with enough force to push out the reward. This defeated the need to learn to use the pipes together since tool combination was not necessary on every trial. Since one pipe was sufficient to dislodge the reward on some trials, it may have been difficult for subjects to understand the need to use two or three pipes in combination to solve the task on other trials in which they did not project the one pipe with enough force to dislodge the reward. Despite the problems this strategy may have created for this experiment, it was nevertheless a clever strategy for solving the task in that it was novel and efficient.

Another problem with this experiment may have been that rewards could always be dislodged through persistent work on the task. It did not matter how many errors were made; as long as the subject continued to insert pipes into the tube the reward would eventually fall out of the tube, or move far enough through the tube for the subjects to reach it manually. Motivation to learn how to combine the pipes may have been quite low since the only benefit from doing so would have been to dislodge the rewards more quickly.

In addition to the one-tool solution strategy and the absence of sufficient motivation to learn to combine pipes, procedural problems may have affected the results. The non-experienced capuchins were difficult to test during this experiment and on many test sessions only completed one or two trials. Squeak and Java became very stressed and upset during separations, and this may have distracted the rest of the group members as well. The subjects' performance may have been affected by this stress, causing them not to pay close attention to the task. In addition, it was not ideal to have subjects work together on some of the trials. Further, the rule for ending trials after a minute without tube contact may have been too strict. A longer period of time without work before ending the trial might have been better. Although it would not have improved subjects' performance, it may have given the non-experienced capuchins a chance to complete those trials that were left unsolved. It is unclear why the subjects without experience left some trials unsolved whereas the experienced subjects did not. Perhaps if they were allowed to return to the task after a longer break, a significant difference would have emerged between the groups for trial completion times and stopping work mid-trial.

It is necessary to take these problems into consideration before drawing any conclusions about the effects of experience on problem-solving from this experiment. Because experience with the materials in the first experiment enhanced the capuchins' performance on that task, it is necessary to explore this effect with another task involving tool modification. A different form of tool modification, which does not present the same problems that were found in this experiment, may shed further light on the role of object manipulation in task performance. The next chapter will present such an experiment.

Chapter 4

Experiment 3: Tool modification task II. Subtractive modification

To further examine the effects of experience on a tool modification task, the current chapter introduces another experiment involving the modification of an object to create a suitable tool for solving the task. The previous two chapters introduced experiments designed to investigate the effects of object manipulation experience on capuchins' initial acquisition of a novel tool behavior, as well as their subsequent performance of that behavior, and on their modification of tools in order to perform that behavior. In the first experiment (Chapter 2), manipulative experience with the task objects proved beneficial; the experienced capuchins dislodged rewards more quickly, after having learned to use the rod as a tool, than the capuchins without such experience. In the second experiment (Chapter 3), in which capuchins had to manufacture the appropriate tool by combining shorter pipes together to make a longer one, manipulative experience did not have any affect on task performance. This is difficult to explain, although there were a number of problems with the experiment that are most likely responsible for this outcome. Therefore, the results were generally inconclusive and further examination of the effects of experience on a different tool modification condition of this task was necessary.

In the current experiment, the capuchins had to subtract a piece from the end of a pipe tool in order to insert the pipe into the tube: the pipes to be used as tools were given 'T' shaped caps on each end that prevented their insertion into the tube. Subjects thus had to remove these caps in order to create a tool with which they could solve the task (see Figure 4.1). This form of tool modification prevented the problem that had occurred in the second experiment, in which subjects were still able to solve the task without modifying the tool, because these pipes could not be inserted into the tube without first removing a cap. Therefore, it was necessary to learn and use the modification technique in order to acquire the reward. In other ways, the task used in this experiment was the same as that used in the two previous

Figure 4.1. Iko removes a 'T' cap from the pipe, thus creating a tool with which he can solve the task.

experiments; solution was achieved by pushing a reward out of a clear tube with a tool.

As in the previous two experiments, the variable of experience was manipulated by providing the experience group with opportunities to manipulate the pipes and tube used in the task. The duration of each manipulative session was extended 15 minutes in order to increase the subjects' opportunities to manipulate the objects. The non-experience group was not given this opportunity. A set of pre-defined, task-oriented behaviors were recorded, similar to the behaviors recorded in the previous experiments, and incorporating behaviors recorded by Visalberghi and Trinca (1989) and Visalberghi et al. (1995) using the same task. The errors scored during this experiment were different from those scored in the two preceding experiments because they were specific to the use and modification of the 'T' capped pipes. Qualitative notes made during the experiment included detailed information about the performance of inefficient task-oriented behaviors. These inefficient behaviors were not scored as errors because they were not direct attempts, however erroneous, to dislodge the reward. Instead, they were behaviors that hindered solution, such as stopping work on the task mid-trial, discarding of the tools, or failing to recognize tool modifications.

Based on the findings of Experiment 1, it was hypothesized that manipulative experience would enhance the capuchins' performance on this task. The nature of the tool modification necessary to dislodge the reward in the current experiment circumvented the problems present in the second experiment, making it necessary to modify the pipe in order to insert it into the tube. Thus, capuchins with manipulative experience were expected to dislodge rewards more quickly, modify tools more efficiently, and make fewer errors than capuchins without experience.

Method

Subjects

The subjects were six of the tufted capuchins already used in Experiments 1 and 2. The three experience group capuchins had also participated in 40 trials on a task requiring them to chose an appropriate tool for solving the same tube task used in Experiment 1 (see Experiment 5, Chapter 6), and Garth had been given an additional opportunity to manipulate the short pipes used in Experiment 2 for the purpose of examining his manipulations more closely (see Experiment 6, Chapter 6). Both of these experiments will be discussed in more detail in Chapter 6. Two of the subjects (Java and Squeak) were dropped from this experiment because they had become too difficult to work with. Java, the youngest subject in the experience group, was a very nervous monkey. He was uncooperative during separations and, over the course of the first two experiments, became increasingly stressed and unhappy when separated into the test cage with only a few other cagemates. A decision was made to drop Java from the study so as not to cause him any more stress. Squeak, although not the youngest subject in the non-experience group, was the least dominant animal in his social group. He was picked on frequently and threatened by the more dominant animals, and this interfered with his testing. In addition, it appeared that the individual attention and food rewards he received during the test sessions increased the tension between Squeak and his dominant cagemates. Eventually Squeak began to avoid the task, so a decision was made to drop him from the study.

The experience and non-experience groups remained the same as in Experiments 1 and 2, barring the loss of one subject from each group. Therefore, each group in this experiment consisted of three subjects. The experience group subjects were: Garth, Zephyr, and Jesse. The non-experience group subjects were: Creepshow, Lee, and Iko. Subjects' housing, diet, and provision of enrichment objects also remained the same as in Experiments 1 and 2.

Materials

The tube apparatus and frames were the same as those used in Experiments 1 and 2. The objects provided for use as tools in the current experiment were all plastic pipes (35 cm in length and 1.3 cm in diameter) with 'T' shaped caps (4.3 cm wide and 2.5 cm high) placed on each end (see Figure 4.2). The caps fit tightly over the ends of the pipes such that it was

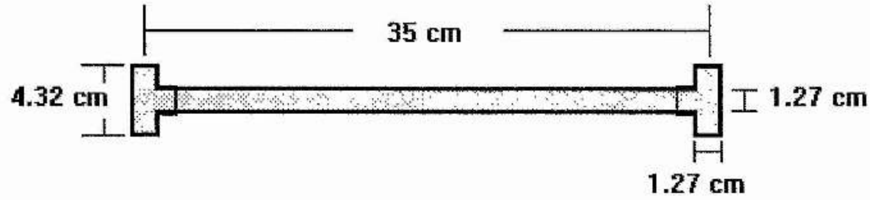


Figure 4.2. 'T' capped pipe.

Table 4.1

Schedule of Manipulative and Test Sessions for Experience Group Subjects

Garth	Zephyr	Jesse[a]
manipulative 1	manipulative 1	manipulative 1
manipulative 2	manipulative 2	manipulative 2
manipulative 3	manipulative 3	manipulative 3
manipulative 4	manipulative 4	manipulative 4
test 1: trials 1-15	**test 1: trials 1-10**	manipulative 5
manipulative 5	manipulative 5	manipulative 6
manipulative 6	manipulative 6	manipulative 7
manipulative 7	manipulative 7	manipulative 8
manipulative 8	manipulative 8	**test 1: trials 1-2**
test 2: trials 16-25	**test 2: trials 11-25**	**test 2: trials 3-24**

[a] Jesse only completed 24 trials instead of 25 because of a miscount of trials during testing. Jesse's trial 2 was unsolved.

necessary to forcibly remove them - they rarely fell off in the absence of applied pressure. These 'T' shaped caps prevented insertion of the pipe into the tube because they were wider than the opening of the tube. Therefore, the pipes could only be inserted into the tube after the caps had been removed.

Procedure

Manipulative sessions

The experience group subjects received a series of 45-minute manipulative sessions before each test session (Table 4.1). Garth and Zephyr each received four manipulative sessions before their first test session, and four manipulative sessions before their second test session. Jesse, however, received all eight manipulative sessions before both of her test sessions. This difference in the schedule of manipulative sessions was largely due to time constraints. Garth and Zephyr cooperated with their separation into the test cage on the first test session, whereas Jesse did not. Garth and Zephyr then worked readily during the first test session, and after completing 10-15 trials each, there was no time left to test Jesse. Therefore, instead of spending another day testing, the rest of the manipulative sessions were given to the group before Jesse was tested on the task.

During the manipulative sessions, the apparatus was mounted inside the cage, but no reward was provided. Three of the 'T' capped pipes were placed on the cage floor. The enrichment objects in the cage were also available, but they were not specifically provided for this experiment. At 15-minute intervals, pipes which had been modified (i.e. the caps had been removed) were reassembled out of subjects' view. Both the reassembled pipes and any pipes that the subjects had thrown out of the cage were then resupplied. A set of pre-defined behaviors (Table 4.2) were recorded during the session and qualitative notes including such information as how the pipes were modified provided supporting details. It should be mentioned that due to the difficulty with observing both activities taking place at the apparatus, and tool modifications taking place elsewhere in the cage, priority was given to those taking place at the apparatus because the majority of pre-defined behaviors were those performed in combination with the tube. Therefore

Table 4.2

Operational Definitions of Behaviors Recorded During Manipulative Sessions

Behavior:	Operational Definition:
Manipulation	Manual handling of an object.
Tool manipulation	Manipulation of the pipe.
Manual contact	Touching the tube with one or more hands.
Tool insertion	Putting the pipe into the tube.
Tool modification	Removal of a 'T' cap from the pipe.
Unmodified-tool contact	Making contact with the tube by means of an unmodified-pipe.
'T' cap contact	Making contact with the tube by means of a 'T' cap.
Modified-tool contact	Making contact with the tube by means of a modified-pipe.
Bout	A series of one behavior performed several times in succession without break or introduction of another behavior.

Table 4.3

Schedule of Test Sessions for Non-Experience Group Subjects

Creepshow	Lee[a]	Iko[b]
test 1: trials 1-14	test 1: trials 1-7	test 1: trials 1-4
test 2: trials 15-19	test 2: trial 8	test 2: trials 5-7
test 3: trials 20-25	test 3: trials 9-12	test 3: trials 8-25
	test 4: (no trials)	
	test 5: trials 13-15	
	test 6: trials 16-20	
	test 7: trials 21-25	

[a] Lee's trials 8, 12, 15, 20, and 25 were unsolved. Lee would not work during the fourth test session. Difficulty in getting Lee to complete the trials was due to her increasingly stressed mood while she was pregnant. [b] Iko's trial 7 was unsolved.

some, possibly many, of the tool modifications may have been missed and the data may represent a lower frequency than was actually performed, however the misrepresentation is consistent across subjects. All animals in the social group had access to the provided materials during the manipulative sessions. The non-experience group did not receive any manipulative sessions, but rather were tested on a continuous schedule until each subject had completed 25 trials (see Table 4.3).

Test sessions

Capuchins in both groups were each tested on 25 trials of the task. At the beginning of each test session, the apparatus was mounted inside the cage and baited as was done in Experiments 1 and 2. A trial began when two 'T' capped pipes were provided on the cage floor or shelf next to the apparatus. Pipes were resupplied during the trial if subjects threw them out of the cage. A trial ended when either the subject dislodged the reward by modifying the pipe and pushing it through the tube, or after 15 to 20 minutes had passed without solution during which the subject was not showing continuous interest in the task (i.e. after an initial period of working on it, they then left the apparatus instead of continuing to work). During those trials, and during any other trials in which subjects were experiencing much difficulty solving the task, the clock was stopped in order to loosen the 'T' caps on the pipes in case they had become stuck and were preventing modification. It is not absolutely clear whether this was the problem in each case, however on many of these trials the caps had become tightly wedged onto the ends of the pipes from the subjects' manipulation of them and were therefore extremely difficult to remove. On some of Lee's trials, extra motivation was used to encourage her to work. This was done because Lee was pregnant and she was losing interest in the task. Fruit rewards were given to Lee's cagemate during those trials, but denied to Lee, in order to increase her motivation to solve the task and get a reward. In most cases, this technique motivated her to finish the trial.

Test sessions typically lasted between 60 and 120 minutes. The number of trials completed per test session varied depending on the subject, the length of each trial, and any interfering social factors. Most subjects completed 25 trials within three sessions of testing, however Lee took seven sessions to complete her trials due to her increasingly stressed mood while she was pregnant. It should be noted that Jesse only completed 24 trials on this task because of a miscount during testing which was realized in retrospect.

Subjects were separated during testing such that only one subject was in the test cage at a time, usually with one or two, but never more than 5, other non-subject animals to keep them company. Exceptions to this were during Garth and Zephyr's first test sessions in which each subject was separated into the test cage individually because they showed no signs of being stressed by the separation. In addition, Zephyr was present during Jesse's second test session because he refused to go into the non-test cage. Non-subject animals typically did not interfere with testing because they were either uninterested in the task, or were threatened away by the subjects. However, on three of Jesse's trials (1, 5, and 6), pipes were modified by other animals.

A set of pre-defined behaviors (Table 4.4) and trial completion times were recorded for each trial. Qualitative notes including such information as how the pipes were modified, when pipes were discarded, when subjects left the apparatus or stopped working, and whether subject's failed to notice tool modifications provided supporting details.

Analysis

The same analyses, the Mann-Whitney U test and the Page Test for Ordered Alternatives, were used as in Experiments 1 and 2 to examine between-group differences and performance trends across blocks of trials. Additionally, the two-tailed Kruskal-Wallis One-Way ANOVA (Siegel & Castellan, 1988) was used to analyze individual differences between the experience group subjects. Blocks of trials consisted of 5 trials each for purposes of comparison with Visalberghi and Trinca (1989) and Visalberghi et al. (1995).

Table 4.4

Operational Definitions of Behaviors Recorded During Test Sessions

Behavior:	Operational Definition:
Tool insertion	Putting the pipe into the tube.
Success	Dislodgment of the reward from the tube after having pushed a pipe through.
Tool modification	Removal of a 'T' cap from the pipe.
Errors:	
Unmodified-tool use	Attempted insertion of an unmodified pipe.
'T' cap insertion	Attempted insertion of a 'T' cap (after modification).
Partially-modified-tool use	Attempted insertion of the unmodified end of a pipe after the other end has been modified.

Results

Manipulative sessions

During the manipulative sessions subjects showed varied amounts of interest in the 'T' capped pipes and the tube. The majority of manipulations for each of the three subjects consisted of tool manipulation (79.3%, *n*=464, of Garth's manipulations; 73.7%, *n*=14, of Zephyr's manipulations; and 87.0%, *n*=200, of Jesse's manipulations; see Figure 4.3). Garth spent more time manipulating objects during the manipulative sessions than did Jesse or Zephyr (see Figure 4.4), and he also devoted at least 8.4% (*n*=49) of his total manipulations to modifying tools. Garth frequently carried the 'T' capped pipes up to a perch and banged them over the surface until one or both of the caps broke off. In addition, he frequently re-capped the pipes after modifying them, and then repeated the modification. Occasionally, Garth banged the pipes over the tube to break the caps off. Another behavior Garth performed with some frequency during manipulative sessions was tool insertion. Approximately 5.8% (*n*=34) of his manipulations consisted of inserting the tools into the tube. The remainder of Garth's object manipulations consisted of 'T' cap and modified-tool contacts with the tube (2.6%, *n*=15, and 1.5%, *n*=9, of his manipulations, respectively). Garth spent very little time manipulating the tube manually during the manipulative sessions in this experiment (2.4%, *n*=14, of his manipulations). Because Garth's manipulative behavior consisted mostly of tool manipulations and because he spent time modifying the tools, a correlation with efficient tool modification during testing was expected.

Jesse did not manipulate the objects as frequently as did Garth (see Figure 4.4b), but nevertheless showed an interest in exploring the pipes and the tube. Although most of Jesse's manipulations were with the pipes, she made very few tool modifications during the manipulative sessions (only 0.9%, *n*=2, of her manipulations). Most of Jesse's manipulations with the tube consisted of tool insertions (5.2%, *n*=12, of her manipulations), 'T' cap and modified-tool contacts (2.6%, *n*=6, of her manipulations each), and manual contact (1.3%, *n*=3, of her manipulations). Jesse rarely combined the unmodified tools with the tube (0.4%, *n*=1, of her manipulations). Because

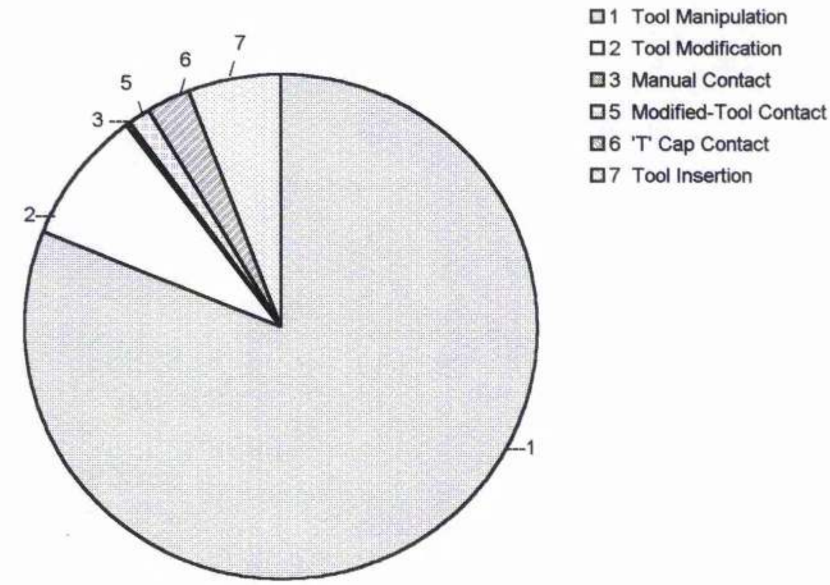


Figure 4.3a. Total number of bouts of manipulation performed by Garth during manipulative sessions.

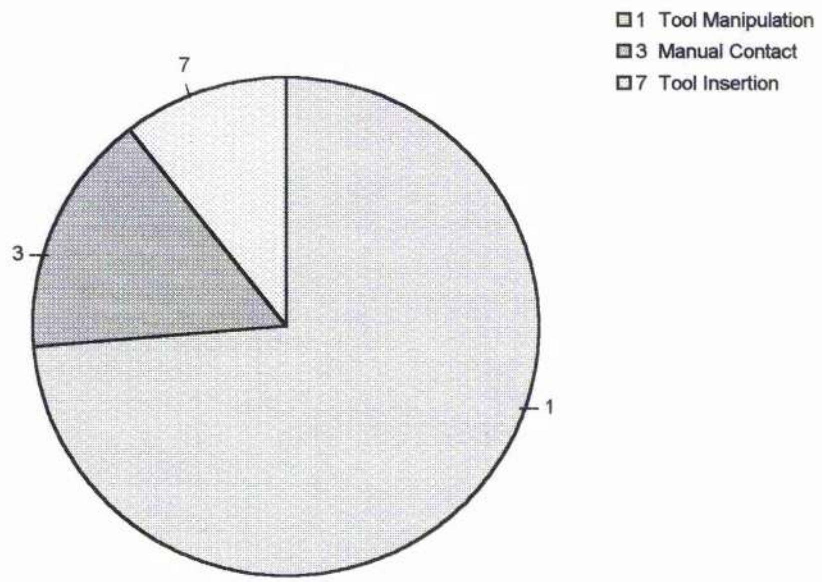


Figure 4.3b. Total number of bouts of manipulation performed by Zephyr during manipulative sessions.

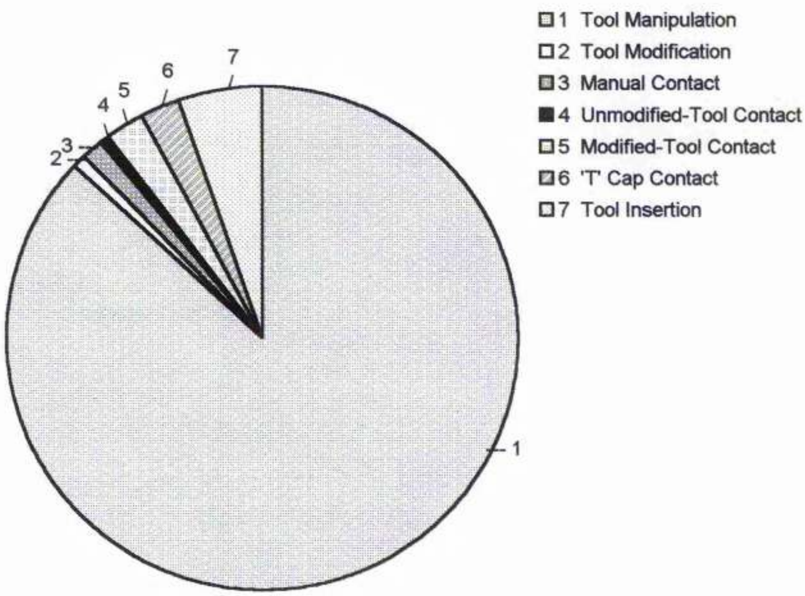


Figure 4.3c. Total number of bouts of manipulation performed by Jesse during manipulative sessions.

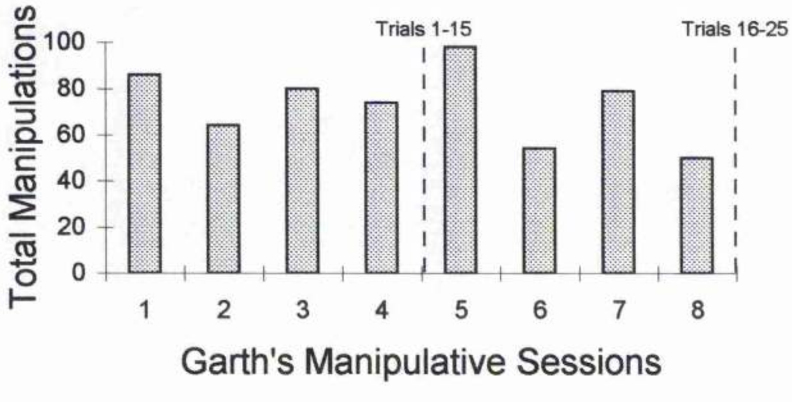


Figure 4.4a. Total number of bouts of object manipulation for each of Garth's manipulative sessions. Note that dotted lines show when test trials were completed.

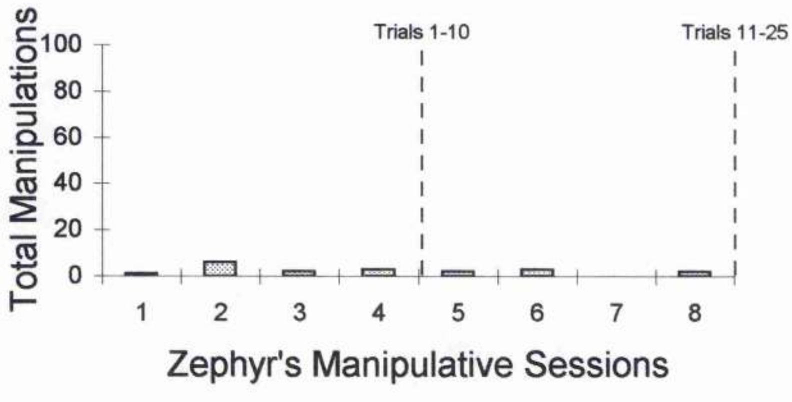


Figure 4.4b. Total number of bouts of object manipulation for each of Zephyr's manipulative sessions.

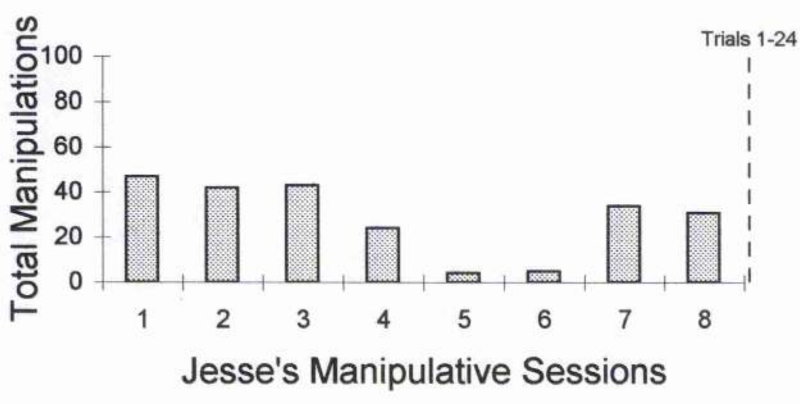


Figure 4.4c. Total number of bouts of object manipulation for each of Jesse's manipulative sessions.

Jesse's manipulative behavior consisted mainly of manipulating the pipes and inserting them into the tube (after they had been modified by Garth), with very few tool modifications, it was not expected that she would modify tools as efficiently as Garth during testing.

Zephyr spent the least amount of time manipulating the objects (see Figure 4.4c). Across sessions he averaged less than 3 manipulations per session. Although most of Zephyr's manipulations were with the pipes, he never modified them. At least, he was never observed to modify tools during manipulative sessions. The remainder of his manipulations consisted of inserting the pipes into the tube (10.5%, n=2, of his manipulations) and contacting the tube manually (15.8%, n=3, of his manipulations). Zephyr's low frequency of pipe and tube manipulations during the manipulative sessions suggested that his performance on the task would not be enhanced by physical exploration experience with the objects.

Test sessions

Despite an increase from the last experiment in the amount of time subjects were given to complete a trial before it ended without solution, subjects in the non-experience group still had more difficulty completing trials than did subjects in the experience group. However, there were fewer unsolved trials in this experiment than in the previous one and one trial was left unsolved by an experience group subject as well. Unsolved trials were not used in the analysis of trial completion times, however they were used for all other analyses. The unsolved trials were: trial 2 for Jesse, trial 7 for Iko, and trials 8, 12, 15, 20, and 25 for Lee. Lee's unsolved trials may be due to her decreasing interest in the task during her pregnancy. Although the non-experience group had more unsolved trials than did the experience group, the difference between them was not significant (mean number of unsolved trials per subject = 2.0 for the non-experience group vs. 0.3 for the experience group; Mann-Whitney U test, U=2.5, ns; Figure 4.5).

Comparison of trial completion times between the groups showed that the experience group dislodged rewards significantly more quickly than did the non-experience group (mean time per subject per trial = 97.1 seconds for the experience group vs. 184.8 seconds for the non-experience group; U=0.0,

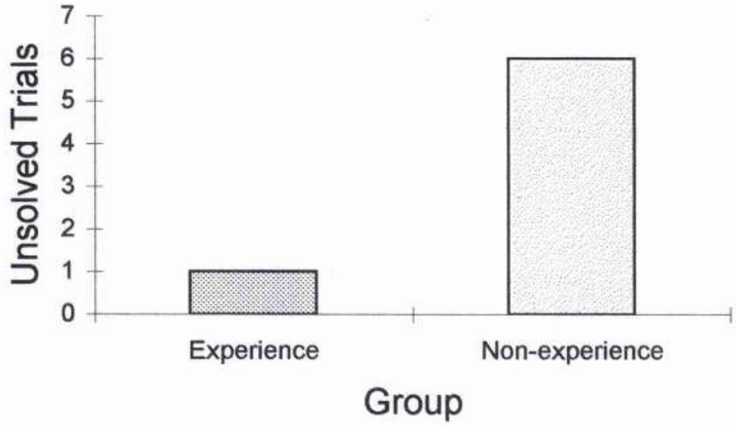


Figure 4.5. Total number of unsolved trials for each group.

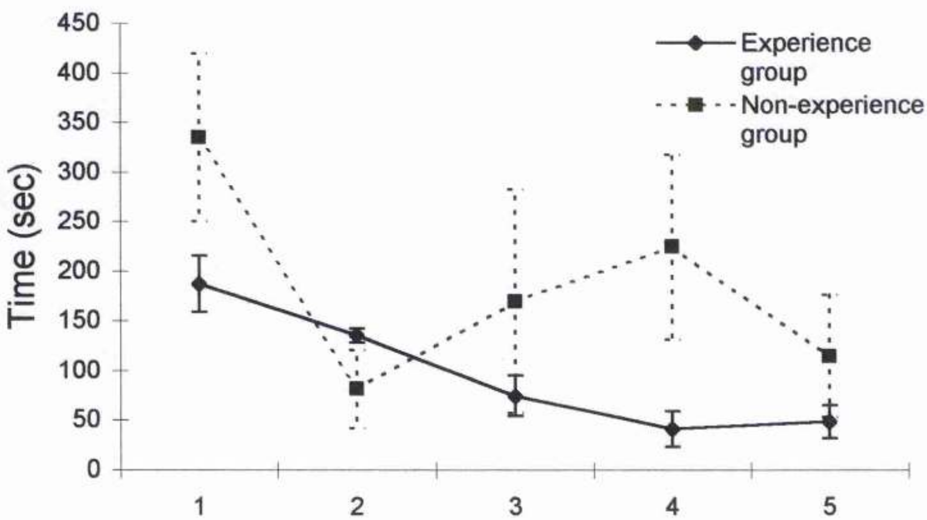


Figure 4.6. Mean trial completion time (±*SE*) per block averaged across subjects for each group.

* Note that blocks consist of 5 trials for each subject except for the following: block 1 consists of 4 trials for Jesse, block 2 consists of 4 trials for Iko and Lee, block 3 consists of 3 trials for Lee, and blocks 4 and 5 consist of 4 trials for Lee.

$p<.05$; Figure 4.6). In addition, the experience group's completion times significantly decreased across blocks of trials whereas the non-experience group's completion times did not (Page Test for Ordered Alternatives, $L=160$, $p<.01$, for the experience group; $L=136$, ns, for the non-experience group).

Frequencies of errors were analyzed next for each group. This analysis revealed no statistically significant differences in error performance between the groups. Unmodified-tool use was the most common error made by all subjects. Most trials began with subjects making this error as they tried to insert the pipe into the tube before attempting to modify it. Unmodified-tool use was performed more frequently by the non-experience group than by the experience group, however the difference was not significant (mean frequency per subject per block = 15.4 for the non-experience group vs. 10.9 for the experience group; $U=4.0$, ns; Figure 4.7). The experience group significantly decreased their performance of this error across blocks of trials, and infrequently attempted to insert unmodified tools in the last two blocks of trials (mean total frequency per subject = 2.7 for trials 16-20 and 2.0 for trials 21-25; $L=162$, $p<.01$). That is, the experience group subjects only attempted to insert unmodified tools a total of six times in the last block of trials. It is interesting to note that Garth did not make this error at all across the last two blocks of trials (trials 16-25) and Jesse only made this error once in each block. Therefore, Zephyr was responsible for making most of the unmodified-tool insertion attempts across the last two blocks of trials. However, whereas all of the experience group subjects decreased their frequency of attempts to insert unmodified tools, the non-experience group did not decrease their performance of this error and persisted in making unsuccessful attempts to insert the unmodified tools across trials ($L=142.5$, ns).

There was reason to hypothesize that Garth should be the most efficient experience group subject at modifying tools during testing because he had the most experience with modifying the tools during manipulative sessions. Efficient tool modification would include a low frequency of attempts to insert the unmodified tools into the tube. Therefore, the individual subjects in the experience group were analyzed for differences in performance of the unmodified-tool use error. Although Garth made this error less frequently than Jesse or Zephyr, the difference between the subjects

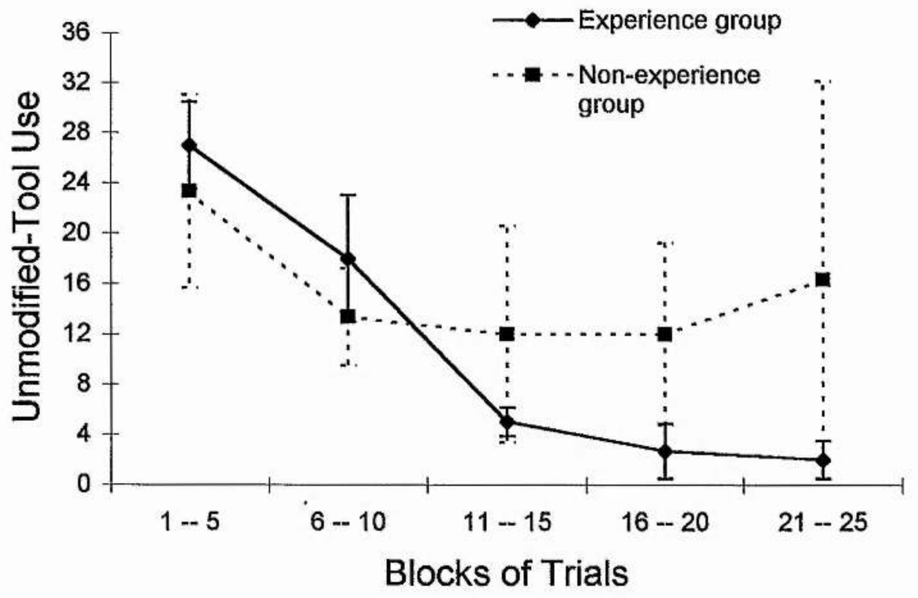


Figure 4.7. Total number of attempts to insert unmodified tools (±*SE*) per block averaged across subjects for each group.

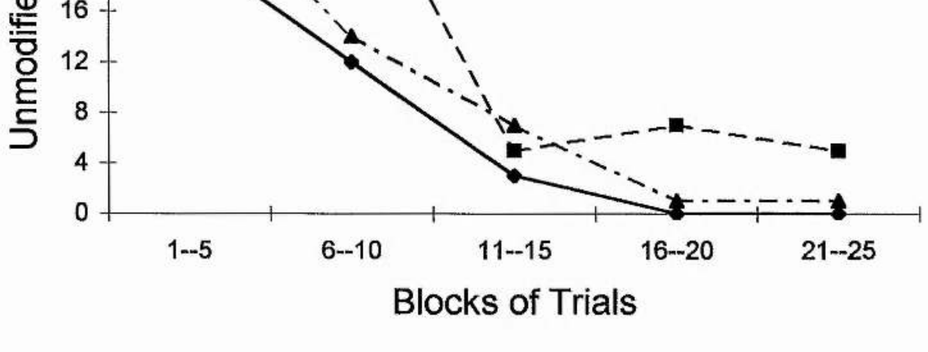


Figure 4.8. Total number of attempts to insert unmodified tools per block for each subject in the experience group.

was not significant (mean frequency = 7.2 for Garth vs. 10.0 for Jesse and 15.6 for Zephyr; Kruskal-Wallis One-Way ANOVA, $\chi^2(2, N=15)=2.12$, ns; Figure 4.8).

'T' cap insertions were made infrequently by both the experience group and the non-experience group subjects and no difference was found between them (mean frequency per subject per block = 1.1 for the non-experience group vs. 0.7 for the experience group; U=2.0, ns; Figure 4.9). Partially-modified-tool use was the least common error made by each group. Although the non-experience group attempted to insert the unmodified ends of partially modified pipes with slightly more frequency, between-group differences were not statistically significant (mean frequency per subject per block = 0.5 for the non-experience group vs. 0.1 for the experience group; U=0.5, p=.068; Figure 4.10).

Inefficient behaviors were then analyzed for each group. *Discarding of a tool*, by dropping or tossing the pipe away from the tube, was the first inefficient behavior. This behavior was performed significantly more frequently by the non-experience group than by the experience group (mean frequency per subject per block = 8.1 for the non-experience group vs. 1.3 for the experience group; U=0.0, p<.05; Figure 4.11). Discarding of tools hindered subjects' solutions because it left them without a means to dislodge the reward from the tube until either they retrieved the discarded tool or picked up a different one. It is interesting to note that tool discards were often accompanied by vocalizations (grunts or cries), or violent banging on the cage or tube, especially among the non-experience group subjects. The infrequent discarding of tools by the experience group significantly decreased across blocks of trials whereas the performance of this behavior by the non-experience group remained consistent across trials (L=151, p<.05, for the experience group; L=137, ns, for the non-experience group).

The second inefficient behavior was *failing to notice the modification of a tool*. This failure to notice a tool modification was evidenced by a lack of visual or manual inspection, or failure to use the pipe immediately after its modification, in addition to the manipulation of another pipe or leaving the apparatus before returning to manipulate the modified pipe again. The non-experience group did this more frequently than did the experience group,

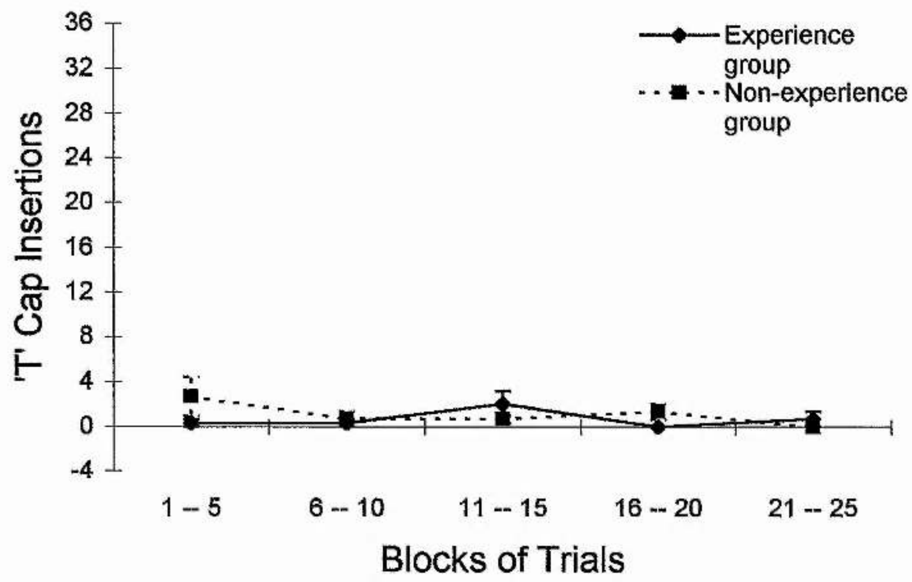


Figure 4.9. Total number of attempts to insert 'T' caps (±*SE*) per block averaged across subjects for each group.

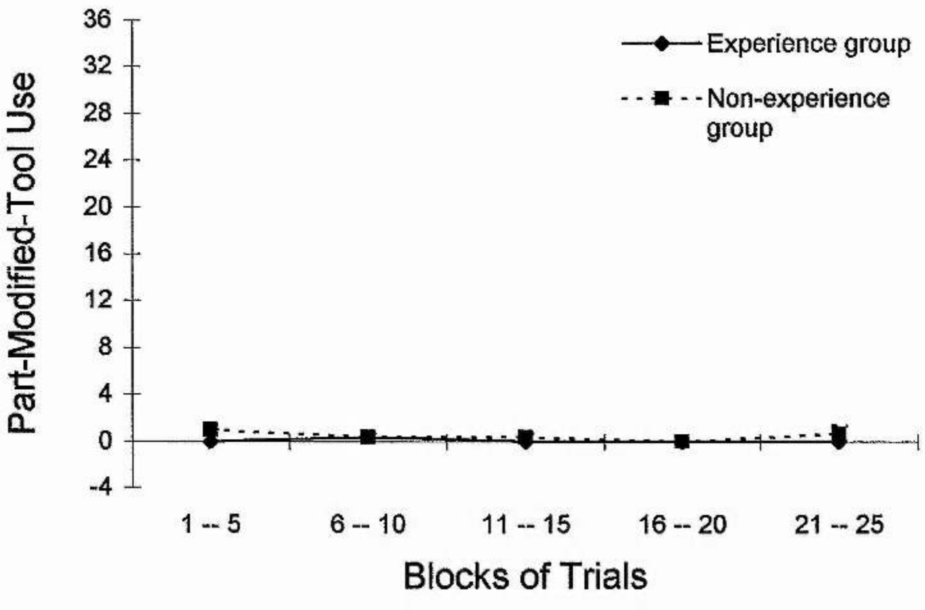


Figure 4.10. Total number of attempts to insert the unmodified end of a partially modified tool (±*SE*) per block averaged across subjects for each group.

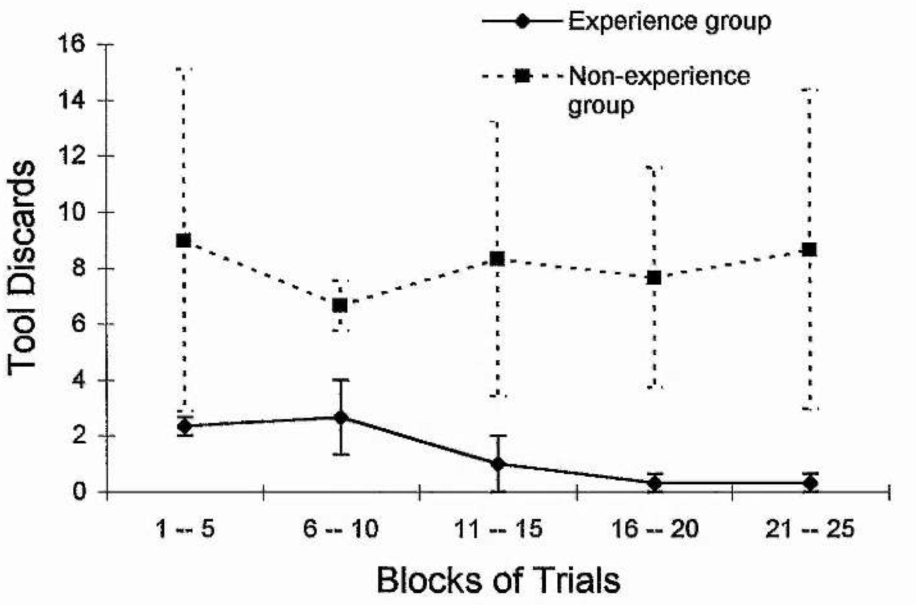


Figure 4.11. Total number of tool discards (±*SE*) per block averaged across subjects for each group.

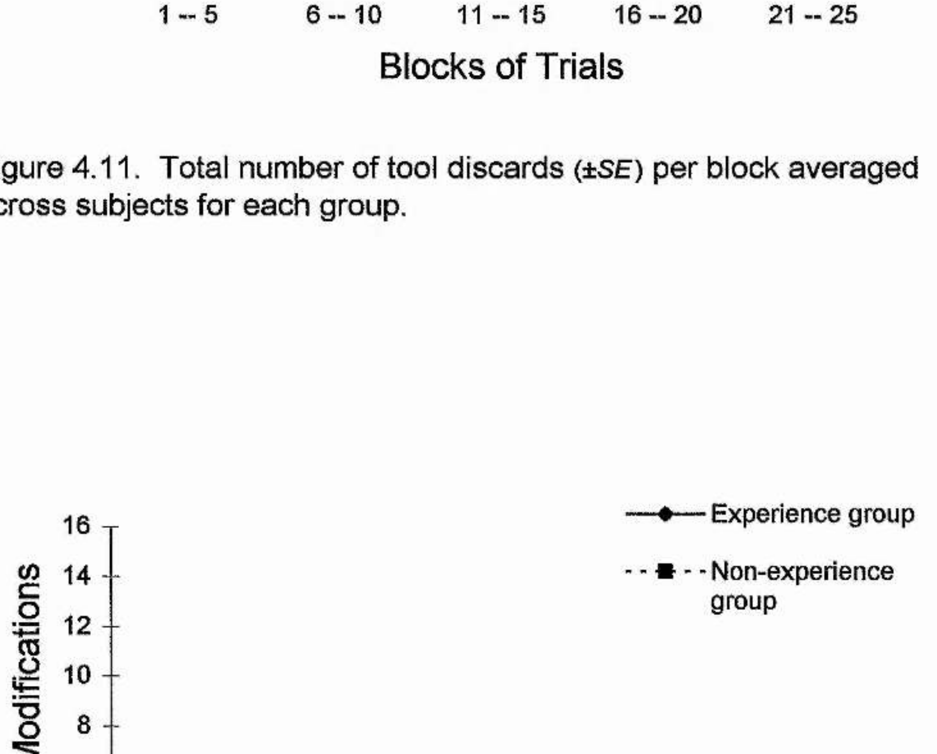


Figure 4.12. Total number of unnoticed tool modifications (±*SE*) per block averaged across subjects for each group.

however the difference between the groups was not significant (mean frequency per subject per block = 1.9 for the non-experience group vs. 0.3 for the experience group; *U*=1.0, ns; Figure 4.12). It should be noted, however, that the experience group never failed to notice modifications during the last 3 blocks of trials (trials 11-25), whereas the non-experience group persisted in their performance of this behavior.

The last inefficient behavior was *stopping work mid-trial*, occurring when a subject either sat with their back to the apparatus or left the apparatus to perform some other behavior. The non-experience group stopped working mid-trial significantly more frequently than did the experience group (mean frequency per subject per block = 3.6 for the non-experience group vs. 0.7 for the experience group; *U*=0.0, $p<.05$; Figure 4.13). Although the experience group decreased their frequency of this behavior across blocks of trials, the trend was not statistically significant (*L*=149.5, ns).

Finally, tool modifications were analyzed for differences between the groups. Data from the qualitative notes showed that two subjects in the experience group routinely modified tools in a more efficient manner than did the rest of the subjects. Garth and Zephyr frequently banged the pipes over the tube or over a perch until at least one of the 'T' caps broke off. Immediately after modifying a pipe, they would insert it into the tube and push out the reward. Garth often did this before attempting to insert the unmodified tool. On the last two blocks of trials, Garth modified the pipes before inserting them on every trial. The other subjects rarely modified tools in an efficient manner. The inefficient modifications performed by the non-experience group subjects included dropping or tossing the pipes away (the same behavior as discarding of the tools, often combined with failing to notice the modification), or sliding the pipes around on the test shelf. To examine modification differences between the groups, the number of trials during which subjects modified the pipes by banging them over the tube was analyzed. Although Garth occasionally carried pipes up to a perch, where he would bang them over the surface until the 'T' caps broke off, and then return to dislodge the reward, this behavior was not included in the analysis because there was insufficient data in the qualitative notes. The experience

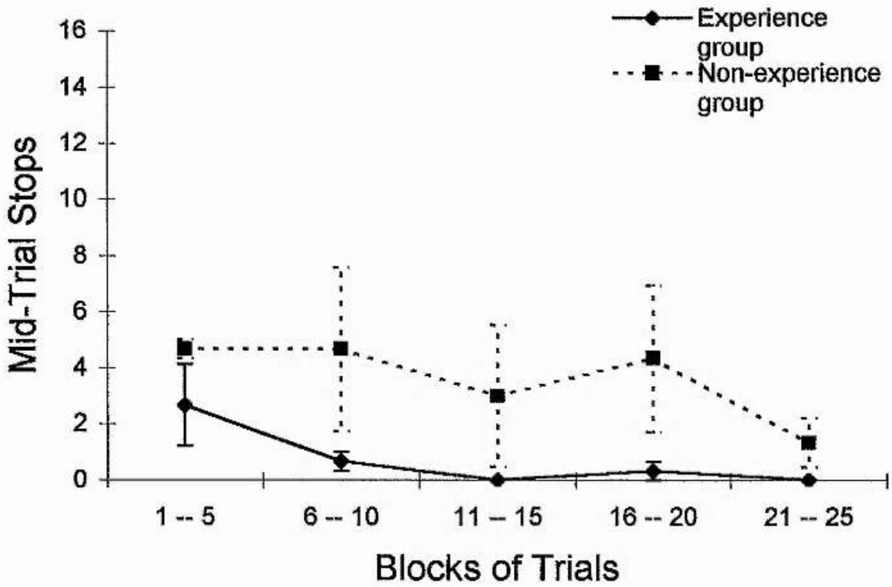


Figure 4.13. Total frequency (±*SE*) per block of stopping work on the task mid-trial averaged across subjects for each group.

group modified tools by banging them over the tube more frequently than did the non-experience group, however the difference was not significant (mean frequency per subject per block = 3.4 for the experience group vs. 0.9 for the non-experience group; *U*=1.0, ns; Figure 4.14).

It is interesting to note that the subject in the experience group who did not modify tools by banging them over the tube or a perch, had an idiosyncratic way of modifying the pipes. Jesse would grip the pipe tightly with two hands, and then bite it halfway between the ends. While doing this, her hands would slide out towards the ends of the pipe and push the 'T' caps off. Jesse seemed to learn this behavior when she first tried biting the pipe and it resulted in its modification because her hands slid off the ends taking the caps off with them. She continued this behavior throughout the experiment. There was reason to hypothesize that Garth would be more efficient than Jesse or Zephyr at modifying tools because he had spent the most time modifying them during the manipulative sessions. An individual analysis of the tool modifications made by banging the pipe over the tube indicated that Garth and Zephyr modified tools in this way significantly more frequently than did Jesse (mean frequency = 5.0 for Garth and 4.8 for Zephyr vs. 0.4 for Jesse; $\chi^2(2, N=15)=10.23$, $p<.01$; Figure 4.15). However, despite this difference in Jesse's tool modification technique as compared with that of Garth and Zephyr's, Jesse's performance was not necessarily less efficient.

Discussion

Initially I had hypothesized that the capuchins with manipulative experience would dislodge rewards more quickly, modify tools more efficiently, and make fewer errors than would the capuchins without such experience. The results from this experiment largely support this hypothesis. The experienced capuchins did dislodge the rewards more quickly than the non-experienced capuchins, as well as improve their trial completion times across blocks of trials. In addition, the experienced subjects worked more efficiently on the task by discarding of tools and stopping work mid-trial less frequently than the non-experienced subjects. However, the experienced capuchins made as many errors on the task as did the non-experienced

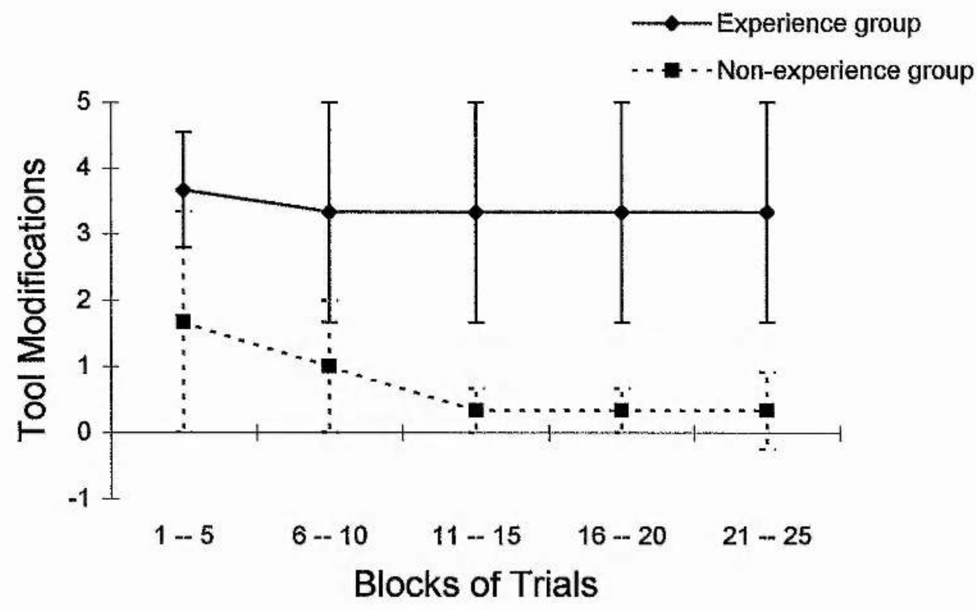


Figure 4.14. Total number of trials (±*SE*) per block during which tool modifications were made by banging the pipe over the tube averaged across subjects for each group.

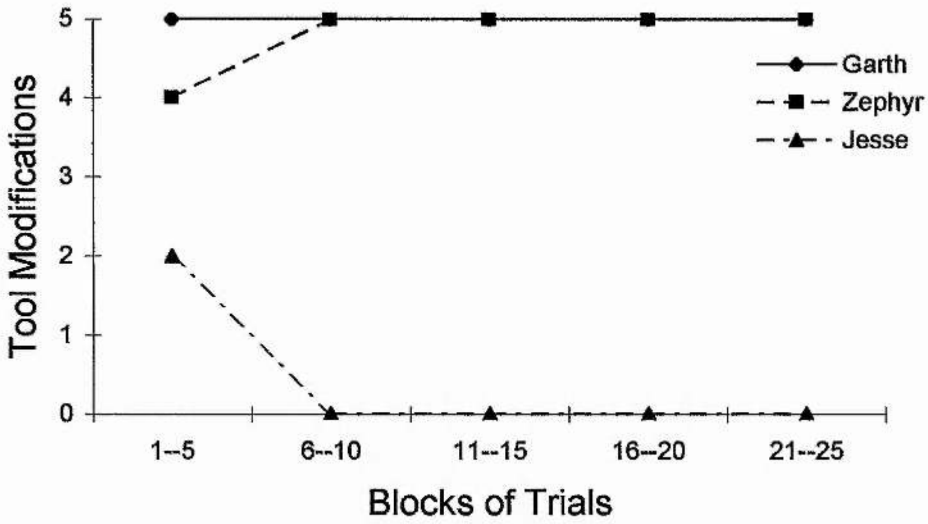


Figure 4.15. Total number of trials per block during which tool modifications were made by banging the pipe over the tube for each subject in the experience group.

capuchins, and failed to notice tool modifications equally as often. The only difference in errors between the capuchins was that those with manipulative experience decreased their attempts to insert unmodified tools across blocks of trials.

Although manipulative experience with the objects used in the task did not affect the occurrence of errors, it did influence the experienced capuchins' performance on the task. Subjects with manipulative experience worked more quickly and more efficiently than did subjects without such experience. The fact that the experienced capuchins discarded tools and stopped working mid-trial less frequently than did the non-experienced capuchins explains their faster completion times. The experienced subjects' decrease in attempting to insert unmodified tools would also explain their improvement in completion times across blocks of trials. Having an effective technique for modifying the pipes could be responsible for their reduced attempts at inserting unmodified tools into the tube. In comparison, a lack of efficient modification techniques may be responsible for the non-experienced capuchins' apparent difficulty with the task, and thus their frequency of discarding tools and stopping work mid-trial.

Despite the experienced capuchins' overall efficient performance on the task, the individual subjects did not appear to gain the same experience from the manipulative sessions. Garth spent the most time modifying tools during the manipulative sessions and was, therefore, expected to be the most efficient subject in the experience group at modifying tools during testing. However, results from the experiment showed that overall Garth made no fewer attempts to insert unmodified tools than did Zephyr or Jesse. Although Garth efficiently modified tools by banging them over the tube more often than did Jesse, he did not use this modification technique any more frequently than did Zephyr. Moreover, while Garth gained experience from physically modifying the pipes during the manipulative sessions and was observed to use the same modification technique during testing, he did not first do so until trial 7 and did not use this technique reliably until his second test session (trials 16-25). In contrast, Zephyr also learned to use the same modification technique during testing, but he first used it on trial 3 and then used it reliably in his second test session (trials 11-25). Bearing in mind his low level of physical exploration of the objects during the manipulative sessions, it is worth questioning whether his performance could have also been influenced by watching Garth manipulate the objects during manipulative and test sessions. However, consistent with Experiment 1 (Chapter 2) and as would be expected from the literature, there was no evidence in this experiment that Zephyr (or any other individual) was able to employ imitation. No subject in either group displayed an efficient modification technique right away; all subjects' first tool modifications occurred inadvertently while manipulating the pipes. However, it cannot be ruled out that stimulus enhancement or social facilitation may have influenced his performance. Zephyr's low level of manipulative experience may explain his slightly higher frequency of attempts to insert unmodified tools into the tube before modifying them. Jesse's performance on the task was similar to that of Garth's in that she modified tools before attempting to insert them into the tube on the majority of trials across the last two blocks. However, her modification technique was very different from that of Garth and Zephyr's and was not learned during the manipulative sessions. Jesse did spend time manipulating the pipes during the sessions, and this apparently influenced her efficient performance on the task, however the exact nature of her experience and its effect are not clear.

Because the capuchins could observe other subjects manipulating tool objects and completing test trials, it is important to acknowledge the potential for social learning effects from stimulus enhancement or social facilitation. These influences have the potential to reduce the effective sample size of each group if subjects learn how to modify a tool more quickly as a result of having observed another subject do so. The problem would be that if, by chance, a subject in one group developed an efficient modification technique earlier than subjects in the other group, and was observed by other group members, then this group as a whole may tend to develop efficient techniques for tool modification more quickly than the other group. However, the first subject in each group to display what later became a reliable and efficient modification technique for that subject did so with nearly equal quickness. In the experience group, Zephyr first modified a tool using his technique on his third trial. He did not begin to use this technique reliably, though, until his 11th trial. In the non-experience group, Iko first modified a tool using his technique on his second trial. He did not begin to use it reliably until his eighth trial. Although there is little difference in the number of trials to first use or start of reliable use of their modification techniques, under the assumption of non-independent subjects, the non-experience group could be expected to perform slightly better if their performance was enhanced by observing Iko's modifications. As the data demonstrated, however, this was not the case, which suggests that independent treatment of subjects may not in fact be statistically invalid for this experiment.

In sum, the results from this experiment suggest that experience with the objects used in a tool task enhances capuchins' performance on that task. One possible explanation for this is that the experience provided subjects with an opportunity to learn about the affordances of the objects and to practice using them in ways related to the task, such as modifying them or inserting them into the tube. This possibility will be explored in more detail in Chapter 6. Despite this effect on the capuchins' performance, however, it remains that the groups did not differ with respect to error frequency. It is possible that the types of errors made in this task were still not sufficiently influential on the outcome of the task to elicit a difference between the experienced and non-experienced conditions. Whereas the task could not be solved without a tool, and thus tool discards influenced subjects' performance, it could be solved despite numerous attempts to insert unmodified tools. If a subject persisted at working on the task then the tool would eventually become modified and the reward would be pushed out of the tube. Errors only delayed solution of the task, but did not completely prevent it. A task incorporating errors that prevent solution might elicit a difference in performance between capuchins with manipulative experience and those without. The next chapter will discuss an experiment that presented this challenge.

Chapter 5

Experiment 4: Penalizing errors

To further investigate the effects of experience on capuchins' tool-using ability, this chapter introduces a task in which the potential for failing to dislodge the reward exists. Results from the previous three experiments varied. In Experiment 1, the basic tube task, the capuchins with manipulative experience typically dislodged rewards more quickly. In Experiment 2, requiring the combination of short pipes to push the reward through the tube, experience with the task materials did not seem to benefit the capuchins. Because it was possible that these results had been influenced by problems with the experiment, including the alternative solution technique of projecting one pipe through the tube, or a lack of motivation to combine the pipes, a third task was used. In Experiment 3, which involved the modification of 'T' capped pipes, the capuchins with manipulative experience dislodged rewards more quickly and more efficiently than the capuchins without such experience. However, despite these monkeys' improvement in error performance, they did not make significantly fewer errors on this task than did those without experience.

One reason why subjects did not differ with respect to error performance in Experiments 1, 2, and 3 may be because the errors made in those experiments did not control the outcome of the tasks. Errors only delayed the solution of the tasks, but did not completely prevent it. A task in which the occurrence of an error makes it unsolvable may have a stronger influence on the performance of experienced (as compared to non-experienced) monkeys, such that experience with the task materials would be beneficial. Therefore, to further explore the effects of experience on capuchin tool use, the current experiment introduced a potential error that prevents successful solution of the task, by adding a trap to the tube.

The trap-tube paradigm was introduced by Visalberghi and Limongelli (1994; see Chapter 1) in order to assess whether capuchins understood the problem created by the task, as opposed to whether they simply recognized the effect produced by inserting a stick into the tube. The trap tube is a variation of the sort of tube used in the previous experiments; a hole is cut out of the bottom of the tube and an enclosed trap is secured onto it (see Figure 5.1). The goal remains the same; a reward is to be pushed out of the tube with a tool. However, on this task the tool must be inserted into the correct side of the tube. A successful solution occurs if the tool is inserted into the side of the tube farthest from the reward (the "correct" side), as depicted in the top picture in Figure 5.2. The reward is then pushed out of the tube, thus avoiding the trap. An unsuccessful solution, or failure, occurs if the tool is inserted into the side of the tube closest to the reward (the "incorrect" side), as depicted in the bottom picture in Figure 5.2. The reward is then pushed over the hole in the tube, thus falling into the trap. It is not possible to obtain the reward once it has fallen into the trap because the trap is enclosed on all sides. Due to the severe penalty of losing the reward for making an error, inserting the rod into the wrong side of the tube, the capuchins need to adopt the correct strategy to dislodge the reward reliably (Visalberghi & Limongelli, 1994).

As in the previous experiments, the variable of experience was manipulated by providing the same group of capuchins with opportunities to manipulate the rods and tube used in the task. More sessions were given during this experiment than during the previous ones in order to provide a sufficient amount of time for subjects to learn about the function of the trap in the tube. The concept of a trap is presumably more difficult to learn than is the technique for modifying a tool. Because no other means were available for helping subjects to learn about the function of a trap, it was hoped that they might discover it through their own exploration if given enough time. As before, the other group of capuchins was not given the opportunity to manipulate the task materials.

A set of pre-defined, task-oriented behaviors were recorded during the experiment; they included any direct manipulations with the apparatus or pipes used in the task. The only error scored in this task was inserting the pipe into the incorrect side of the tube and pushing the reward into the trap. This was recorded as a *failure* since it ended the trial without successfully dislodging the reward. A series of behaviors involving subjects' attention to the task while solving and their reaction after losing the reward to the trap

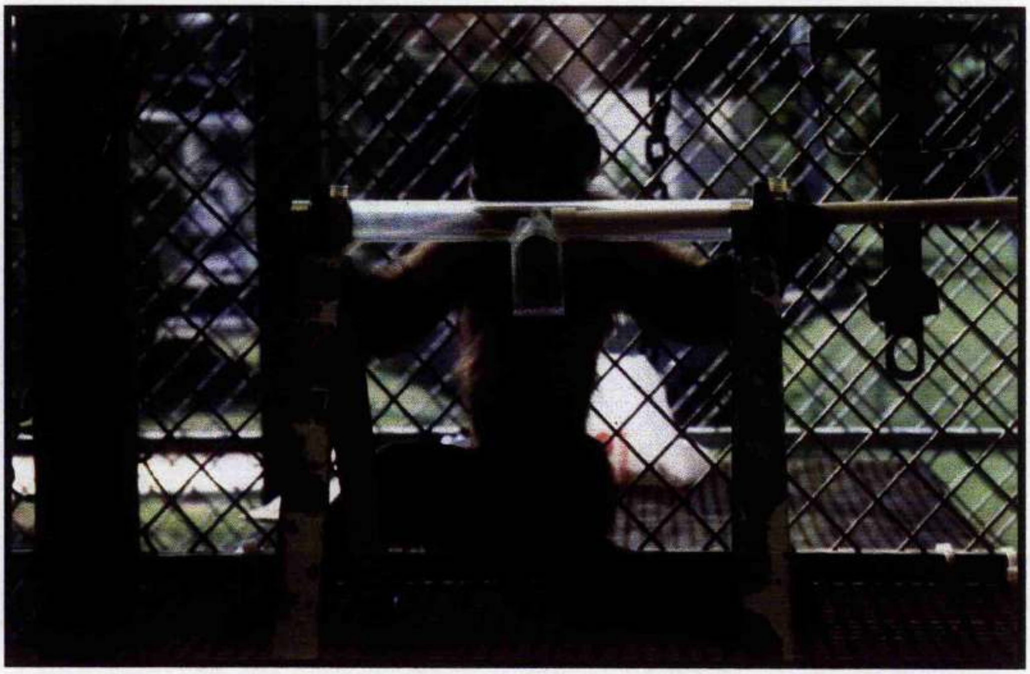


Figure 5.1. Garth carefully attempts to dislodge the reward from the trap tube.

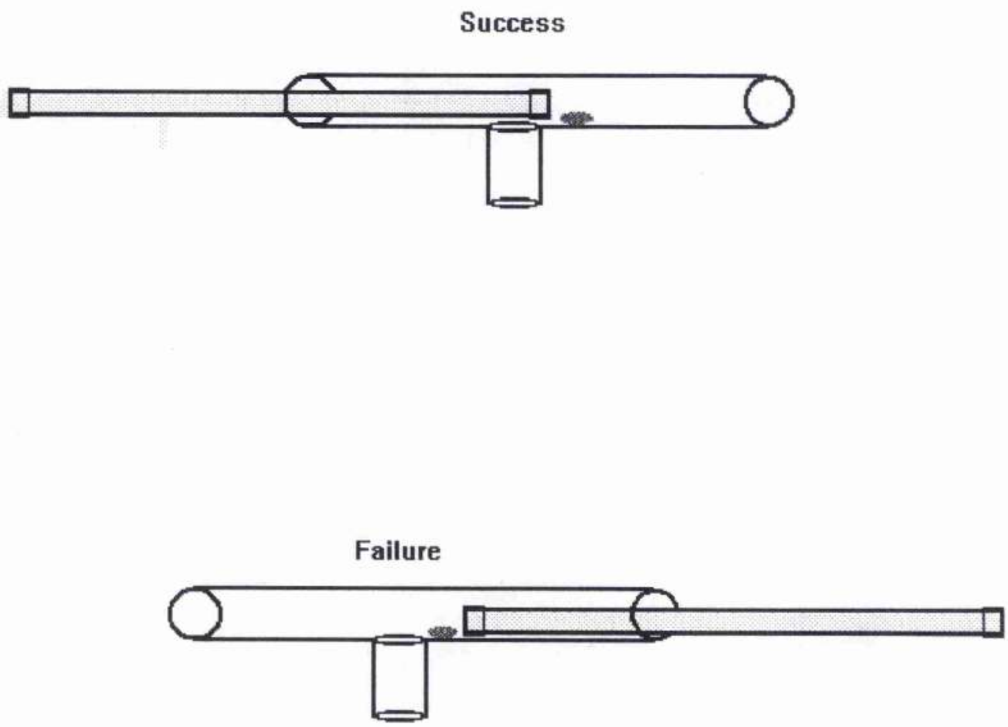


Figure 5.2. Possible outcomes of the trap-tube task. The top tube shows a successful solution in which the tool is inserted into the end of the tube farthest from the reward, therefore pushing the reward out of the tube. The bottom tube shows a failure in which the tool is inserted into the end of the tube closest to the reward, therefore pushing the reward into the trap, instead of out of the tube.

were also scored. The behaviors incorporated those recorded by Visalberghi and Limongelli (1994) and Limongelli et al. (1995) using the same task.

Based on the findings from Experiments 1 and 3, as well as from Visalberghi and Limongelli (1994), it was hypothesized that manipulative experience with the objects used in this task would facilitate the capuchins' performance on the task. Specifically, capuchins with manipulative experience were expected to perform above chance on this task. Additionally, the experienced capuchins were expected to pay more attention to the reward's position in the tube and its movement through the tube while working on the task. Because the task required particular attention to be paid to the positions of the reward and the tool, it was thought possible that successful solutions might take longer than unsuccessful ones. Alternatively, if the capuchins understood how to solve the task, then successful solutions might have been as quick as unsuccessful ones. Therefore, no predictions were made regarding differences in trial completion times between the groups.

Method

Subjects

The subjects were the same six capuchins already used in Experiment 3 (as well as in Experiments 1 and 2). The three experience group subjects had also participated in a choice task involving the tube task used in Experiment 1 (see Experiment 5, Chapter 6), and Garth had been provided the opportunity to further manipulate the short pipes used in Experiment 2 (see Experiment 6, Chapter 6). The experience and non-experience groups remained the same as in Experiment 3 (barring the death of Garth's mother, Greta, who had previously been part of his social group). The subjects' diet also remained the same. Housing was different for this experiment because subjects had been moved into their summer accommodation. The experience group was housed in an outdoor enclosure consisting of two cages (each measuring 2.5 m wide x 3 m deep x 2.5 m high) joined by a sliding guillotine door. Testing of the subjects took place in one of these outdoor cages and will be referred to as the "test" cage. The test cage was not always the same cage, though, because conflict arose in the social group during this experiment, resulting in Zephyr being attacked by others in his group part-way through the experiment, and Zephyr refused to go into one of the cages to be tested, whereas Garth refused to go into the other cage. Therefore, Zephyr and Jesse were tested in the same cage each time, whereas Garth began his testing in the same cage that Zephyr and Jesse were tested in, and then completed his testing in the other cage. The set up was the same for both cages. Similarly, the apparatus was set up alternatively in either cage partway through the manipulative sessions to allow both Zephyr and Garth access to the materials in their preferred cages.

The non-experience group was housed in a large outdoor enclosure (a corncrib, measuring 4.2 m high and 5 m in diameter). Two small cages were connected to the main enclosure for the purpose of holding the monkeys while the corncrib was cleaned, and used in this experiment to separate the social group while testing a subject. One cage (measuring 1.3 m wide x 1.8 m deep on one side, 2.3 m deep on the other side x 1.8 m high) was connected to the corncrib by a sliding cage door, and the other cage (measuring 1.2 m wide x 1.7 m deep x 1.8 m high) was connected to the first small cage by a short run (measuring 0.3 m wide x 0.6 m deep x 0.4 m high) with a solid sliding door on either end. Testing of the subjects took place in the corncrib itself and will be referred to as the "test" cage.

Both groups' enclosures contained perches in addition to a selection of enrichment objects including balls, swings, barrels, and chains. The variety of enrichment objects were always present and were not removed during testing.

Materials

The apparatus was a transparent plastic tube (35 cm in length and 2.4 cm in diameter) with a closed-bottom trap (4.9 cm in length and 2.6 cm in diameter) attached to the underneath of the tube via a hole cut in the center of the tube (see Figure 5.3). The tube was mounted in a metal frame - the same frame used for the non-experience group in Experiments 1, 2, and 3. The objects provided for use as tools were all plastic rods (each 35 cm in length and 1.3 cm in diameter). They were created by capping the ends of

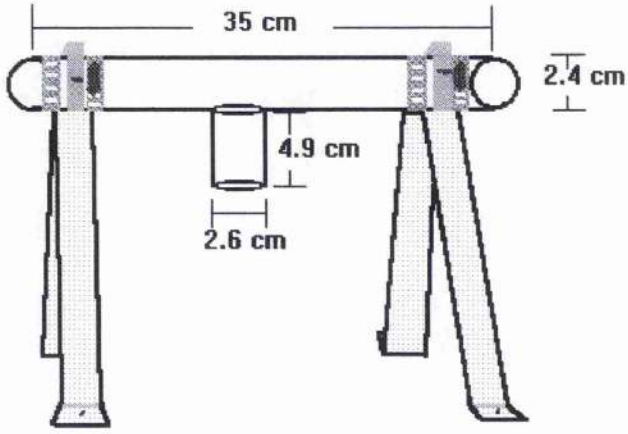


Figure 5.3. Trap tube apparatus.

Table 5.1

Schedule of Manipulative and Test Sessions for Experience Group Subjects

Garth	Zephyr	Jesse
manipulative 1-10	manipulative 1-10	manipulative 1-10
test 1: trials 1-10	**test 1: trials 1-3**	**test 1: trials 1-8**
manipulative 11-20	**test 2: trials 4-10**	**test 2: trials 9-10**
test 2: trials 11-16	manipulative 11-20	manipulative 11-20
test 3: trials 17-20	**test 3: trials 11-13**	**test 3: trials 11-20**
manipulative 21-30	**test 4: trials 14-20**	manipulative 21-30
test 4: trials 21-30	manipulative 21-30	**test 4: trials 21-30**
manipulative 31-40	**test 5: trials 21-30**	manipulative 31-40
test 5: trials 31-40	manipulative 31-40	**test 5: trials 31-40**
manipulative 41-50	**test 6: trials 31-40**	manipulative 41-50
test 6: trials 41-50	manipulative 41-50	**test 6: trials 41-50**
test 7: trials 51-80	**test 7: trials 41-50**	

pipes to keep rewards from becoming lodged inside. Small rocks that fit easily into the tube and trap were also provided for subjects to insert into the tube during the manipulative sessions. The enrichment objects were available for use, although they were not specifically provided for this experiment.

Procedure

Manipulative sessions

The experience group subjects received a series of ten 30-minute manipulative sessions before each of ten test sessions (see Table 5.1). During the manipulative sessions, the apparatus was mounted on a wire shelf inside the test cage, but no reward was provided. Four rods were placed on the shelf next to the apparatus. On the ninth manipulative session, and on all subsequent sessions, four small rocks were placed on the wire shelf with the rods. The rocks were provided for insertion into the tube because subjects rarely inserted chow into the tube. They were intended to help the subjects learn about the function of the trap, by pushing the rocks through the tube or into the trap, without the distraction of a reward. A set of pre-defined behaviors (Table 5.2) were recorded during the session.

In general, the subjects were not separated from their non-subject cagemates during manipulative sessions; thus, all animals in the social group had access to the rods, rocks, and tube. However, during the 19th manipulative session, the subjects were separated from their cagemates into the test cage in an effort to increase their manipulation of the tube. However, they did not manipulate the tube more frequently and were rejoined with the rest of their group halfway through the session. On the 26th through 30th manipulative sessions, all animals (subject and non-subject) in the group were closed into the test cage in an effort to increase manipulation of the apparatus, however, this did not work either. The non-experience group did not receive any manipulative sessions. Instead, they were tested on a continuous schedule until each subject had completed 50 trials (see Table 5.3).

Table 5.2

Operational Definitions of Behaviors Recorded During Manipulative Sessions

Behavior:	Operational Definition:
Manipulation	Manual handling of an object.
Tool manipulation	Manipulation of the rod.
Manual contact	Touching the tube with one or more hands.
Tool contact	Making contact with the tube by means of the rod.
Tool insertion	Putting the rod into the tube.
Object insertion	Putting a rock or a piece of chow into the tube.
Success	Dislodgment of a rock or a piece of chow from the tube by pushing the rod through the tube.
Failure	Loss of a rock or a piece of chow to the trap by pushing the rod through the tube.
Bout	A behavior performed several times in succession without break or interpolation of a behavior of another type.

Table 5.3

Schedule of Test Sessions for Non-Experience Group Subjects

Iko	Creepshow	Lee
test 1: trials 1-22	test 1: trials 1-6	test 1: trials 1-9
test 2: trials 23-40	test 2: trials 7-16	test 2: trials 10-14
test 3: trials 41-50	test 3: trials 17-18	test 3: trials 15-25
	test 4: trials 19-31	test 4: trials 26-30
	test 5: trials 32-40	test 5: trials 31-50
	test 6: trials 41-50	

Test sessions

Test sessions were conducted with both groups until subjects completed 50 trials each. At the start of each session, the apparatus was mounted inside the test cage. A lab coat was placed over the apparatus and the tube was baited while hidden from subjects' view. The side of the tube into which the reward was placed, or in other words, the side of the trap to which the reward was placed, was randomly alternated across trials. This controlled for success due to a bias towards inserting rods into a particular side of the tube. The tube was baited with a piece of fruit during the first test session, but the properties of the fruit reward were such that it could be pushed over the trap without falling into it. So, on subsequent sessions, half of a peanut was used as a reward. Any trials on which the reward was pushed over the trap without falling into it were discarded and the subject was retested. A rod was placed on the shelf next to the apparatus, although on many trials subjects removed the rod from the experimenter's hand before it was placed on the shelf. A trial began when the subject picked up the rod. The reason for this was because there was often a delay before subjects in the non-experience group came to the apparatus since their test cage was larger than the experience group's test cage. The starting point of each trial remained the same across subjects when this criterion was used. A trial ended when the subject either succeeded in successfully dislodging the reward, or failed to do so by pushing the reward into the trap. After every failed trial, the subject was given the opportunity to explore the trap tube. This period of exploration lasted between 0 and 180 seconds.

A set of pre-defined behaviors (Table 5.4) and trial completion times, whether success or failure, were recorded for each trial. Qualitative notes including information about the level of attention paid to the task, the subject's reaction after pushing the reward into the trap, and the side of the tube into which the rods were inserted provided supporting details. Test sessions typically lasted between 60 and 120 minutes, and the number of trials completed during each session varied depending on the subject, the length of the trial, and social factors interfering with testing. However, each experience group subject completed 10 trials after every 10 manipulative sessions. Experience group subjects were individually separated from their

Table 5.4

Operational Definitions of Behaviors Recorded During Test Sessions

Behavior:	Operational Definition:
Manual contact	Touching the tube with one or more hands.
Tool contact	Making contact with the tube by means of the rod.
Insertion	Putting the rod into the tube.
Partial insertion	Insertion of the rod into the tube without reaching the reward, or without pushing the reward either out of the tube or into the trap.
Success	Dislodgment of the reward from the tube by pushing the rod through the tube.
Failure	Loss of the reward to the trap by pushing the rod through the tube.

social group during testing. Non-experience group subjects were separated into the test cage with a few cagemates because it was not possible to separate them individually. Because their cage was quite large and the non-subject animals had less interest in the task, they typically stayed to the top or back of the cage, away from the apparatus, and did not interfere with testing. Non-subject animals that approached the apparatus and attempted to interfere with testing were threatened away.

After each subject had completed 50 trials, Garth (one of the experience group subjects) was given the opportunity to complete 30 more trials. He was given these extra trials because he was the only subject who had removed incorrectly inserted tools and reinserted them into the correct side of the tube to solve the task. This behavior suggested that Garth may have been paying particular attention to the positions of the reward and tool in the tube during these trials, and thus may have been close to understanding the nature of the problem. Therefore, by providing him with the opportunity to complete more trials, it was hoped that his performance on the task would improve. Garth was not given any more manipulative sessions.

Analysis

The same analyses, the Mann-Whitney U test and the Page Test for Ordered Alternatives, were used as in Experiments 1, 2, and 3 to examine between-group differences and performance trends across blocks of trials. Additionally, the Spearman correlation coefficient was used to analyze correlations between success and trial completion time, and the binomial test was used to assess the statistical significance of successful versus failed solutions (the null hypothesis being 50% success) and left versus right insertion side biases. Blocks of trials consisted of 10 trials each for purposes of comparison with Visalberghi and Limongelli (1994) and Limongelli et al. (1995).

Results

Manipulative sessions

Subjects showed less interest in the tube and rods during the manipulative sessions in this experiment than in the three previous experiments. The total number of object manipulations for each subject for each block of 10 manipulative sessions is approximately the same as the total number of manipulations they had made during each *individual* session in the previous experiments (see Figure 5.4). Garth spent more time manipulating objects during the sessions than did Zephyr or Jesse, and was the only subject to insert rocks or chow into the tube (3.4%, *n*=12, of his manipulations). Garth also showed fairly consistent interest in the materials across sessions, whereas Zephyr and Jesse manipulated the objects most frequently across the first 20 sessions, and then rarely across the following 30 sessions.

The majority of manipulations for all three subjects consisted of tool manipulation (54.5%, *n*=195, of Garth's manipulations; 72.5%, *n*=29, of Zephyr's manipulations; and 50%, *n*=32, of Jesse's manipulations; see Figure 5.5). The majority of their manipulations with the tube consisted of manual contacts (20.9%, *n*=75, of Garth's manipulations; 15%, *n*=6, of Zephyr's manipulations; and 25%, *n*=16, of Jesse's manipulations) and tool insertions (17.6%, *n*=63, of Garth's manipulations; 12.5%, *n*=5, of Zephyr's manipulations; and 14.1%, *n*=9, of Jesse's manipulations). Garth and Jesse both made non-insertion tool contacts with the tube as well (3.6%, *n*=13, of Garth's manipulations and 10.9%, *n*=7, of Jesse's manipulations).

Although Garth inserted rocks or chow into the tube, therefore baiting the tube, a total of 12 times across the manipulative sessions, he only inserted a rod into a baited tube on nine occasions. On the first of these insertions, during the first block of manipulative sessions, Garth pushed the object into the trap. Across the last three blocks of manipulative sessions, Garth pushed the objects into the trap two more times, but he successfully pushed the object out of the tube six times. Garth was the only subject to gain experience with pushing objects out of the tube or into the trap during manipulative sessions. It was expected that this experience would influence

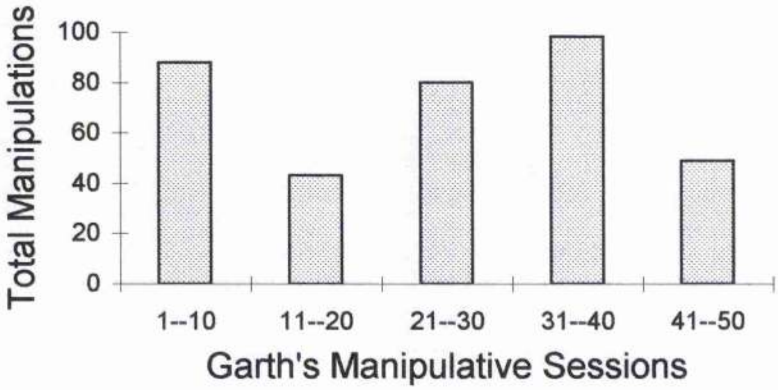


Figure 5.4a. Garth's total number of bouts of object manipulation for each block of ten manipulative sessions. Note that ten trials were completed after each block of manipulative sessions.

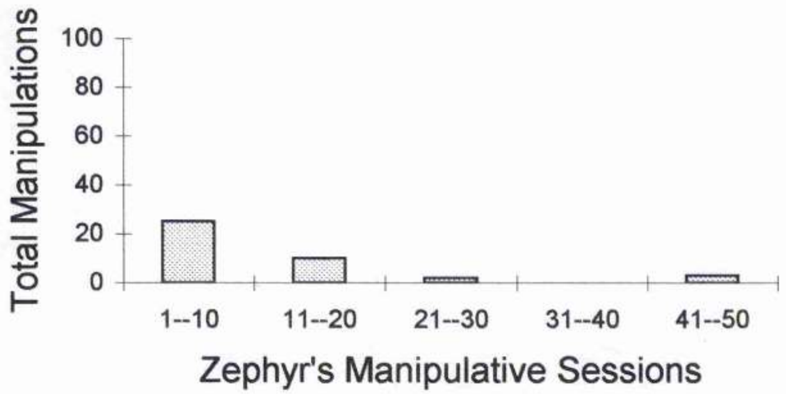


Figure 5.4b. Zephyr's total number of bouts of object manipulation for each block of ten manipulative sessions.

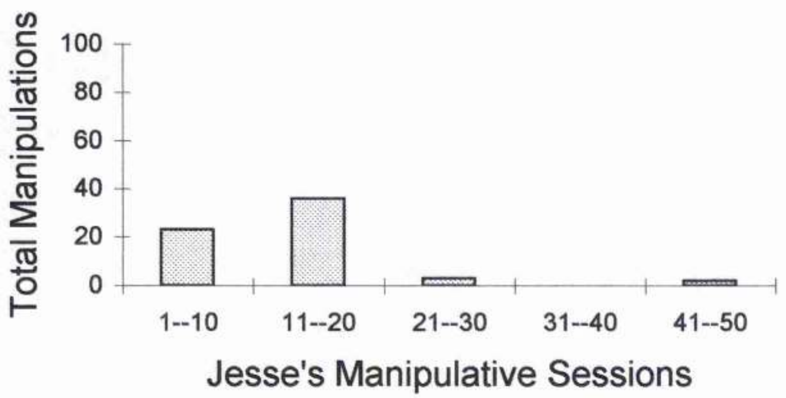


Figure 5.4c. Jesse's total number of bouts of object manipulation for each block of ten manipulative sessions.

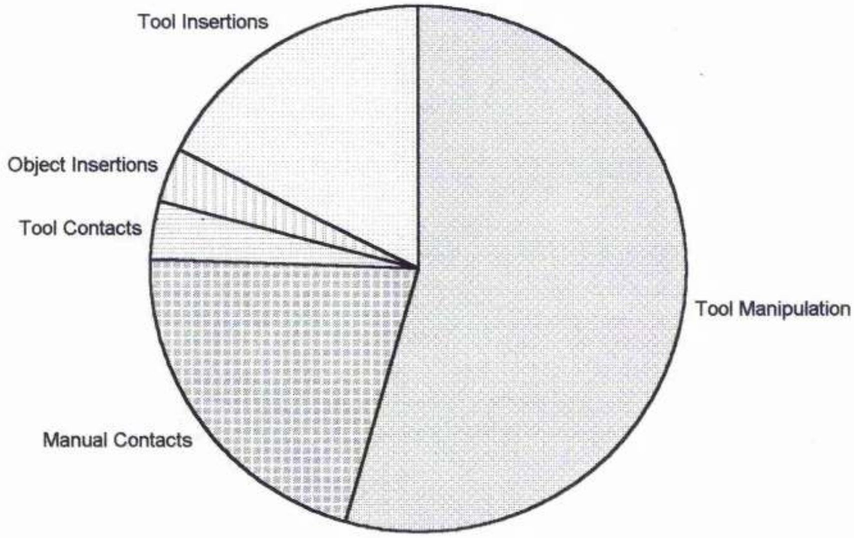


Figure 5.5a. Total object manipulations performed by Garth during manipulative sessions.

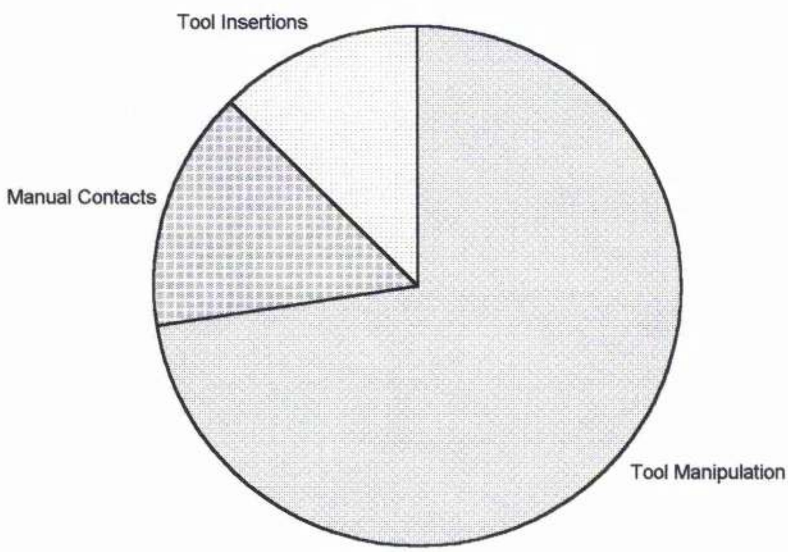


Figure 5.5b. Total object manipulations performed by Zephyr during manipulative sessions.

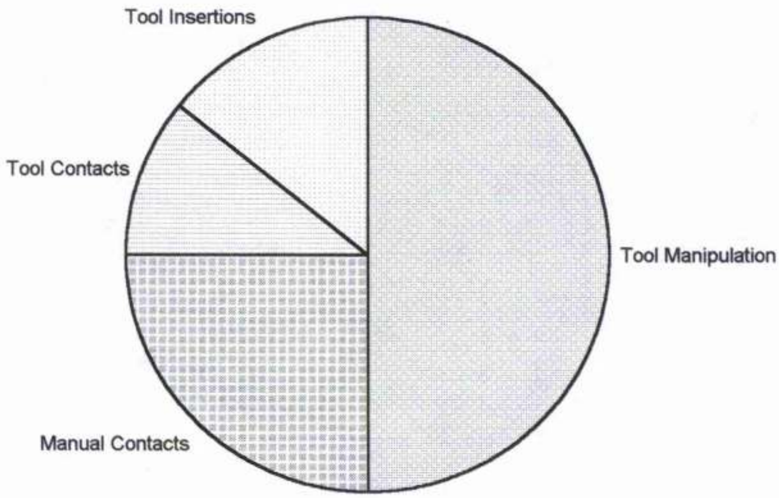


Figure 5.5c. Total object manipulations performed by Jesse during manipulative sessions.

his success during testing. Because Zephyr and Jesse did not push inserted objects through the tube during the manipulative sessions, it is hard to predict whether they learned anything about the function of the trap through their exploration of the apparatus.

Test sessions

All subjects completed 50 trials on this task; however, no subject performed significantly better than that expected from chance insertion. That is, no subject dislodged rewards on significantly more than 50% of the trials - the same level of success achieved through systematic insertion of the rod into the same side of the tube on every trial, or insertion into one of the two sides on every trial by chance (see Table 5.5). One subject in the non-experience group, Creepshow, solved significantly below chance (50%) on the task (binomial test, N=50, p<.05). Although the non-experience group's performance was slightly below that of the experience group, the difference between the groups when the number of successful trials were compared was not statistically significant (mean number of successful trials per subject per block = 5.5 for the experience group vs. 4.2 for the non-experience group; Mann-Whitney U test, U=0.5, p=.07; Figure 5.6). Despite Garth's opportunity to complete 30 more trials on the task, his performance remained at chance level (binomial test, N=80, ns).

Trial completion times were analyzed for each group. The experience group spent slightly more time working on each trial than did the non-experience group, however the difference was not significant (mean time per subject per trial = 14.7 seconds for the experience group vs. 12.1 seconds for the non-experience group; U=4.0, ns; Figure 5.7). Although the experience group's completion times increased across blocks of trials, the trend was not significant either (Page Test for Ordered Alternatives, L=146, ns). Furthermore, there was no significant correlation between completion time and success for either group (Spearman correlation coefficient, r_s=0.8208, ns, for the experience group; r_s=-0.6325, ns, for the non-experience group; Figure 5.8).

Because performance was at chance level for subjects in both groups, insertion side biases were analyzed. A bias towards inserting the rods into

Table 5.5

Percentage of Successful Trials Per Block

Subject			Trials			
Experience Group	1-10	11-20	21-30	31-40	41-50	1-50
Garth	50.0	50.0	60.0	50.0	70.0	56.0
Zephyr	60.0	50.0	70.0	50.0	50.0	56.0
Jesse	60.0	50.0	30.0	70.0	60.0	54.0
Non-Experience Group						
Iko	50.0	40.0	10.0*	40.0	50.0	38.0
Creepshow	50.0	30.0	10.0*	30.0	50.0	34.0*
Lee	50.0	50.0	70.0	50.0	50.0	54.0
		Extra	Trials			
	51-60	61-70	71-80	1-80		
Garth	50.0	50.0	70.0	56.3		

* $p<.05$.

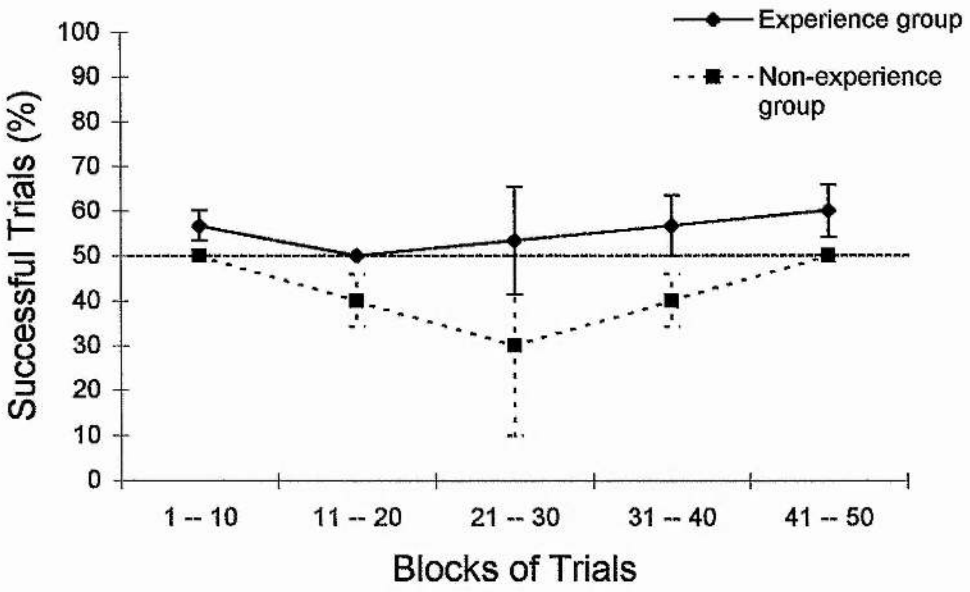


Figure 5.6. Percentage of successful trials (±*SE*) per block averaged across subjects for each group. 50% is chance performance.

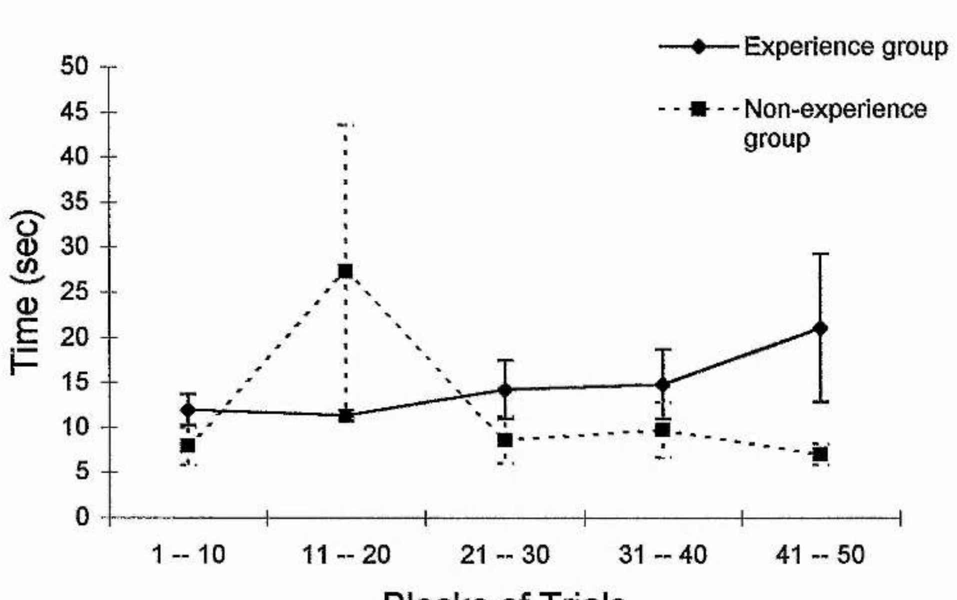


Figure 5.7. Mean trial completion time (±*SE*) per block averaged across subjects for each group.

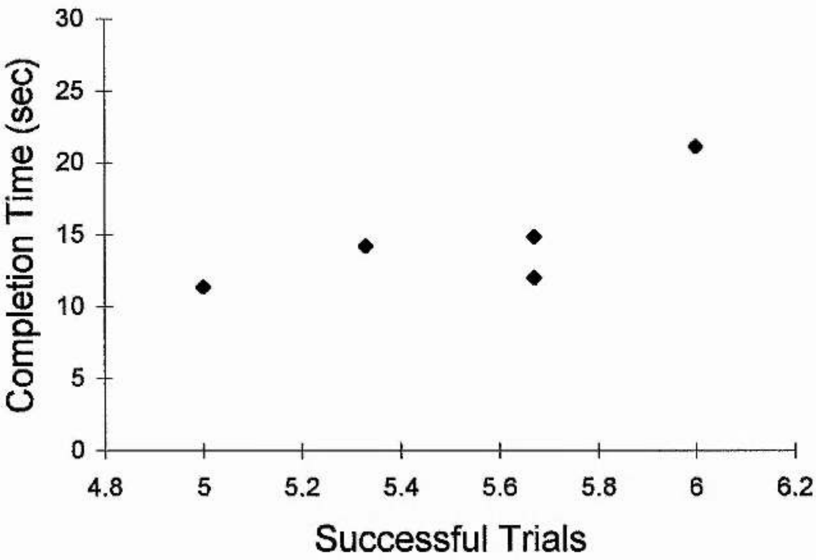


Figure 5.8a. Completion times plotted against number of successful trials per block for the experience group.

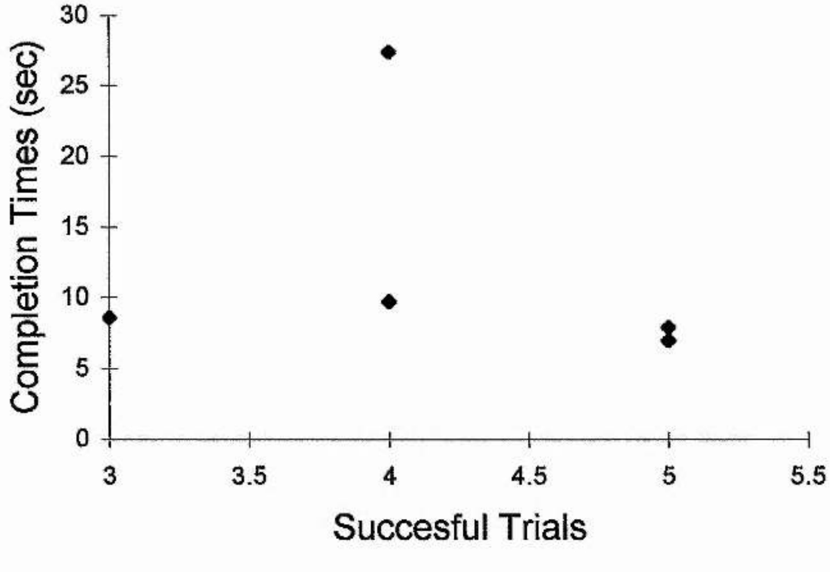


Figure 5.8b. Completion times plotted against number of successful trials per block for the non-experience group.

the same side of the tube on each trial would lead to chance performance, and success above chance automatically removes any strong side bias for tool insertions. Every subject except for Garth had strong and significant preferences for inserting rods into a particular side of the tube (Table 5.6). Zephyr made 100% of his insertions into the left side of the tube (binomial test, N=50, p<.01). Jesse, Lee, and Iko all made significantly more insertions into the right side of the tube than into the left side (binomial test, N=50, p<.01 for Jesse and Lee; N=55, p<.01 for Iko). Creepshow did not have an overall insertion side bias on the task, however he did insert significantly more rods into the left side of the tube across the first 25 trials (binomial test, N=24, p<.01) and then switched his bias and inserted significantly more rods into the right side of the tube across the last 25 trials (binomial test, N=24, p<.01). On two trials, Creepshow did not insert a rod at all, but rather shook the tube until the reward fell into the trap. Garth did not have any bias towards inserting tools into either side of the tube (binomial test, N=53, ns).

In the light of Garth's lack of an insertion side bias, it is interesting to note that he is one of only two subjects who removed rods and reinserted them into the other side of the tube during a trial, and the only subject who ever did so correctly. Garth removed partially inserted rods from the incorrect side of the tube (the side which was closest to the reward, therefore leading to a failed solution if the insertion was completed) and reinserted them into the correct side of the tube (the side which was farthest from the reward, therefore leading to a successful solution when the insertion was completed) to dislodge the reward on three occasions across the last block of trials. During the 30 extra trials Garth was given at the end of the experiment, he removed one more incorrectly inserted rod and reinserted it into the correct side of the tube to dislodge the reward. It should be noted, though, that Garth removed one partially inserted rod from the correct side of the tube and reinserted it into the incorrect side of the tube, thus failing to dislodge the reward, during those 30 trials. In addition, he removed 13 incorrectly inserted rods from the tube and then reinserted them into the same, incorrect side. Although it was thought that Garth was paying more attention to the reward and tools' positions in the tube after he had correctly reinserted three rods at the end of the first 50 trials, his extra 30 trials did not support this

Table 5.6

Percentage of Insertions into the Right Side of the Tube

Subject	Trials 1-25	Trials 26-50	Total
Experience Group			
Garth	32.0	42.9	37.7
Zephyr	0.0**	0.0**	0.0**
Jesse	100.0**	88.0**	94.0**
Non-Experience Group			
Iko	96.3**	75.0**	85.5**
Creepshow	20.8**	79.2**	50.0
Lee	100.0**	92.0**	96.0**

** $p<.01$.

interpretation. Garth made many more incorrect tool reinsertions (that is, reinserting incorrectly inserted tools into the same incorrect side) across the last 30 trials, than he did correct reinsertions across all 80 trials. However, it is possible that Garth was paying more attention to this relevant feature of the task, but did not fully understand the causal relations involved. Iko, the other subject to remove and reinsert tools, did so less frequently than did Garth. He removed a correctly inserted rod from the tube during the fourth block of trials and reinserted it into the incorrect side, thus failing to dislodge the reward. Iko also removed four incorrectly inserted rods from the tube and reinserted them into the same incorrect side across the first three blocks of trials. His performance was as unconvincing as was Garth's for developing a successful solution strategy by paying attention to the reward and tools' positions in the tube.

Three behaviors were analyzed to determine how much attention subjects were paying to the task while working. It was of particular importance in this task to notice the position of the reward with respect to the trap. The first behavior consisted of looking at the reward before working on the task (*pre-solution looks*). This included looking inside the tube, through one or both ends, and looking directly at the reward through the outside of the clear tube. No subject in either group did this consistently throughout the trials. Though, two subjects in the experience group did look at the reward before solving frequently across the last block of trials. Garth looked at the reward on every trial and Jesse looked at it on seven out of ten trials. Although the experience group looked at the reward before working on the task more frequently that did the non-experience group, the difference was not significant (mean frequency per subject per block = 2.2 for the experience group vs. 0.4 for the non-experience group; U=2.0, ns; Figure 5.9). Whereas the non-experience group failed to look at the reward before working on the task consistently across trials, the experience group increased their frequency of pre-solution looks across blocks of trials, however the trend was not significant (L=140, ns).

The second behavior was looking at the reward mid-solution (*mid-solution looks*). This included looking inside the tube, through one or both ends, and looking directly at the reward through the outside of the tube while

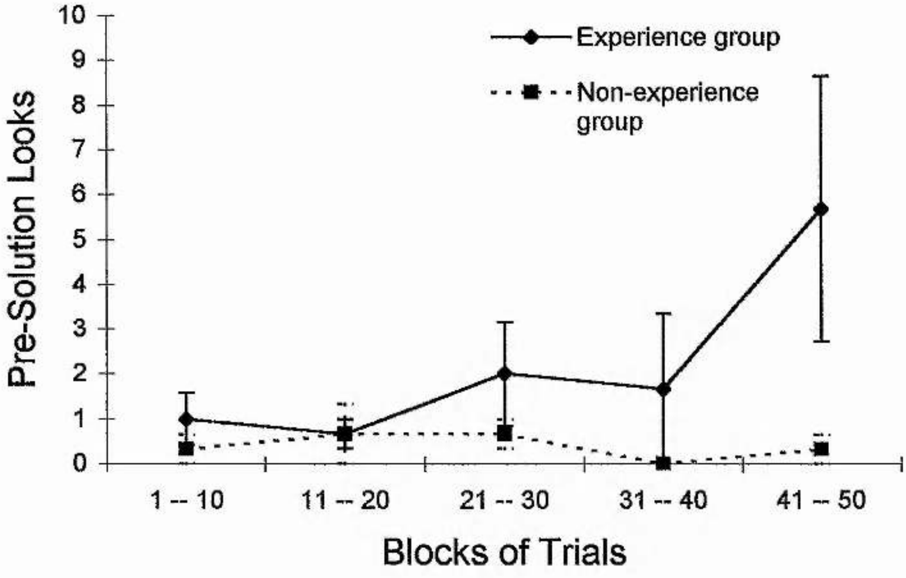


Figure 5.9. Number of trials (±*SE*) per block on which subjects looked at the reward before working on the task, averaged across subjects for each group.

working on the task, usually after a partial insertion was made. Again, subjects did not look at the reward consistently throughout the trials. Garth was the only subject to look at the reward on more than half of the trials in each block across the last three blocks of trials. Although the experience group looked at rewards mid-solution more frequently than did the non-experience group, the difference was not significant (mean frequency per subject per block = 2.3 for the experience group vs. 0.7 for the non-experience group; U=2.0, ns; Figure 5.10). Further, the experience group increased their frequency of mid-solution looks after about 20 trials, but the trend was not significant (L=144, ns).

The third behavior consisted of following the reward's movement through the tube while working on the task (*reward follows*). Subjects did this either with their hand cupped under the tube or with their eyes tracking the movement of the reward. No subject in either group did this consistently across trials. The experience group followed the reward's movement through the tube more frequently than did the non-experience group, however, the difference was not significant (mean frequency per subject per block = 2.1 for the experience group vs. 1.1 for the non-experience group; U=3.0, ns; Figure 5.11). Further, both groups slightly increased their frequency of reward follows across trials, but the trends were not significant (L=145.5, ns, for the experience group; L=148, ns, for the non-experience group).

Subjects' reactions to losing the reward to the trap were recorded for each trial on which they failed to dislodge the reward. There were three task-oriented behaviors which they performed after these trials. The first behavior was attempting to catch the reward as it fell into the trap (*catch attempts*). Subjects would cup their hand underneath the tube as if they expected the reward to fall through the trap. Subjects in the non-experience group only did this occasionally across the last two blocks of trials, whereas subjects in the experience group made catch attempts more often. However, there was no significant difference between the groups for performance of this behavior (mean frequency per subject per block = 1.1 for the experience group vs. 0.5 for the non-experience group; U=2.0, ns; Figure 5.12).

After the reward had fallen into the trap subjects occasionally investigated the trap with their hands and mouth (*trap contact*), or continued

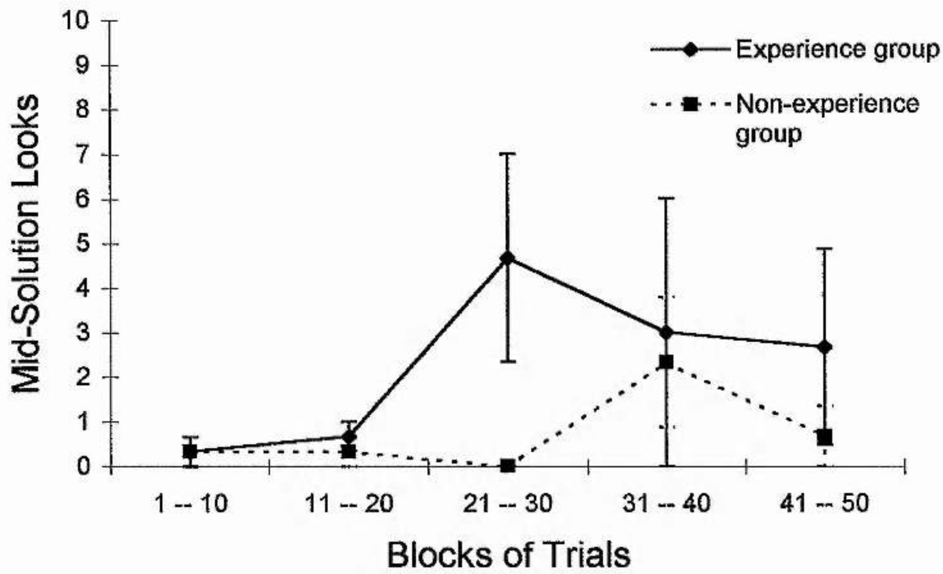


Figure 5.10. Number of trials (±*SE*) per block on which subjects looked at the reward in the middle of working on the task, averaged across subjects for each group.

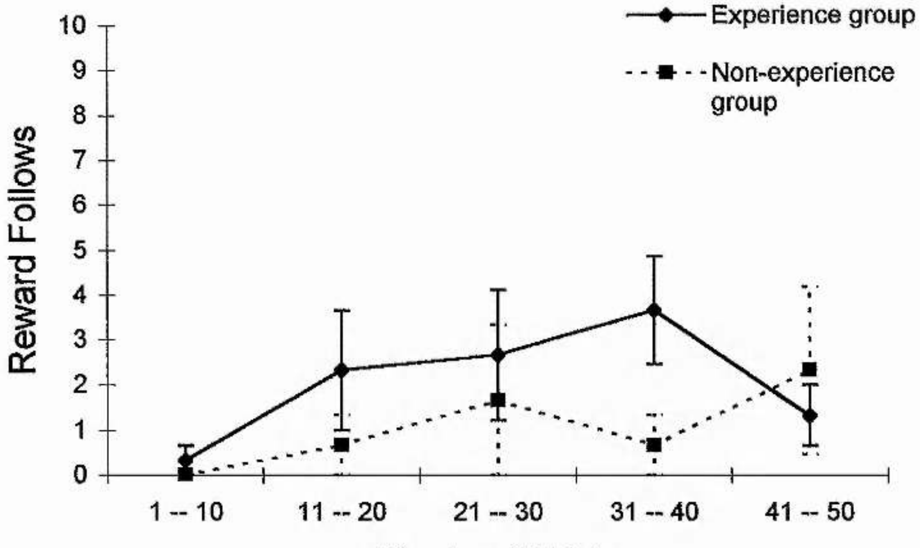


Figure 5.11. Number of trials (±*SE*) per block on which subjects followed the reward's movement through the tube, averaged across subjects for each group.

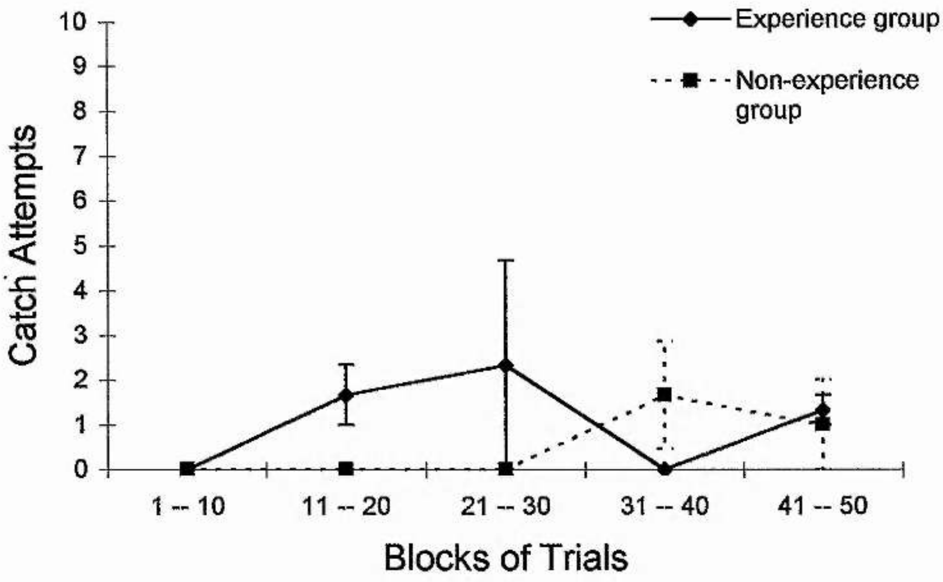


Figure 5.12. Number of trials (±*SE*) per block on which subjects attempted to catch the reward as it fell into the trap, averaged across subjects for each group.

to probe with the rod remaining in the tube or with a rod they reinserted into the tube (*post-trial insertions*). The experience group performed these last two behaviors after losing the reward more often than did the non-experience group, doing so on approximately half of the failed trials. However, there was no significant difference between the groups for trap contact after failing to dislodge the reward (mean frequency per subject per block = 2.6 for the experience group vs. 1.2 for the non-experience group; U=2.0, ns; Figure 5.13). Nor, was there a significant difference between the groups for post-trial insertions after failing to dislodge the reward (mean frequency per subject per block = 2.3 for the experience group vs. 1.3 for the non-experience group; U=1.0, ns; Figure 5.14). The non-experience group did, however, decrease their frequency of post-trial insertions across blocks of trials, whereas the experience group did not (L=154, p<.05, for the non-experience group; L=149, ns, for the experience group).

Discussion

My initial hypotheses were that the capuchins with manipulative experience would perform above chance on the trap tube task and pay more attention to the task while working than would the capuchins without such experience. The results from this experiment do not support these hypotheses. No subject in either group dislodged rewards above chance and the non-experienced capuchins achieved the same frequency of success as did the capuchins with experience. Further, there were no differences in trial completion time or attention paid to the task while working. And subjects in both groups had the same reactions towards the tube after failing to dislodge the reward.

Object manipulation experience did not influence the capuchins' performance on this task. Perhaps it is not surprising that the experience had no influence considering that the experience group manipulated objects relatively infrequently during the manipulative sessions in this experiment as compared to those of the previous experiments. It is not clear why this was the case. However, as was mentioned earlier in the chapter, there was some social tension between the experience group subjects during the experiment and this may have interfered with their exploration of the task materials.

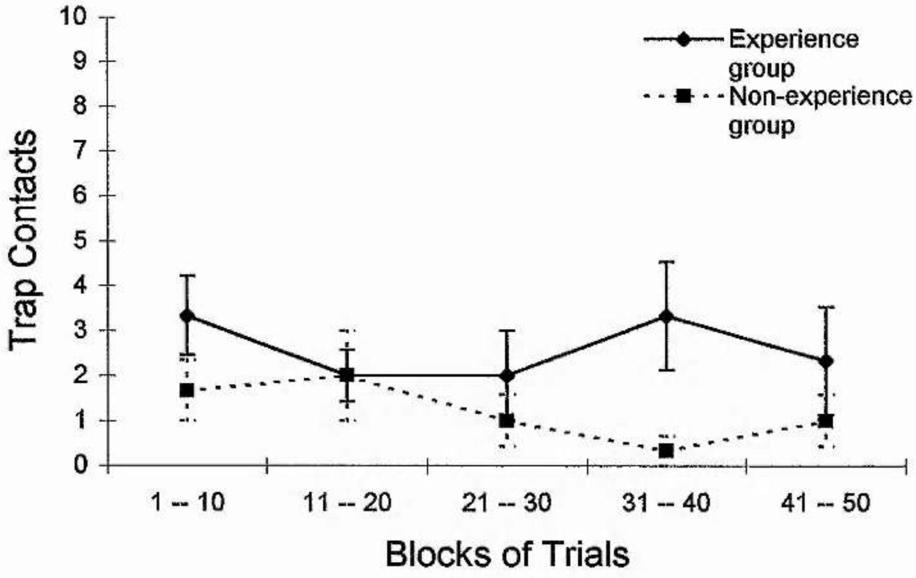


Figure 5.13. Number of trials (±*SE*) per block on which subjects touched or mouthed the trap after the reward fell into it, averaged across subjects for each group.

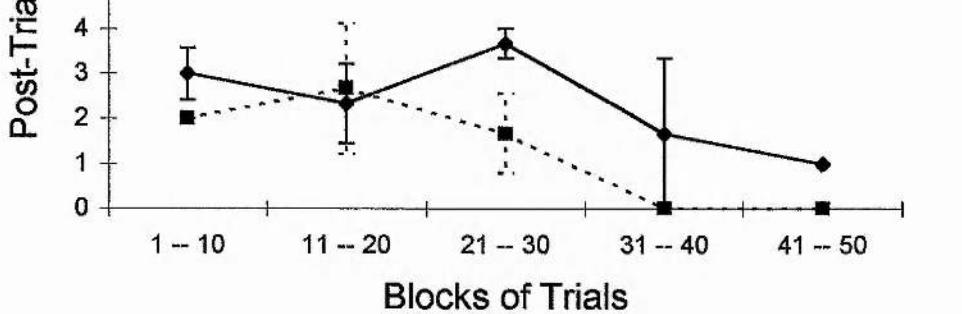


Figure 5.14. Number of trials (±*SE*) per block on which subjects inserted or probed a rod into the tube after failing to dislodge the reward, averaged across subjects for each group.

Garth and Zephyr typically avoided each other, especially after Zephyr was attacked, and this may have limited their exposure to the apparatus during manipulative sessions because neither subject would go near it if the other subject was in that cage.

It is possible that experience with the materials used in this task was not sufficient for subjects to learn about the function of the trap. The only means available to them to learn about the trap were either to investigate it manually or to insert objects into the tube and then push them through with a rod. Since manual investigation was limited to the outside of the trap, it was difficult for subjects to investigate the hole in the tube which connected it with the inside of the trap, and to learn how this tube was functionally different from the previous ones. Garth was the only subject who inserted objects into the tube and pushed them through with a rod. This was perhaps the best way available to learn about the function of the trap, by watching some objects fall into it and other objects avoid it. Still, Garth did not appear to fully learn about the trap's function from this experience, as his performance remained at chance. This suggests that simple exploration of the task materials was not sufficient to facilitate successful performance on this task.

The nature of the trap-tube task was much more complex than that of the previous three tasks. In the first task, subjects had to learn how to insert a rod into a tube. This was easily done during the manipulative sessions. In the second two tasks, subjects had to learn how to combine or modify pipes to insert them into the tube. Again, this could easily be done during the manipulative sessions. In the trap-tube task, subjects had to learn the function of the trap, or at least how to avoid pushing the rewards into it. The trap could not be freely manipulated like the rods could since it was secured to the tube. The actions that could be performed on the trap were also limited because it was attached to the tube. Therefore, this task required that subjects had both an understanding that objects fall downwards, as well as an understanding that there was a hole in the tube, although they could not manually investigate it, through which the reward would fall into an enclosed container from which it could not be obtained. It is possible that the experience provided was not sufficient to increase the capuchins' knowledge about the trap and that a different type of experience would have been necessary to elicit an effect.

An alternative way to view this, though, is that the trap-tube task was inherently too complex for the capuchins and no amount of experience would improve their performance. Perhaps no subject performed above chance because this task was at their upper limit of performance. In Visalberghi and Limongelli's (1994) study with capuchins using this same task, only one subject out of four performed above chance. She did not do so until after having completed 80 trials, however, and further examination of her performance revealed that she had been using a distance-based rule (insert the stick on the side farthest from the reward) to solve the task. Therefore, Visalberghi and Limongelli (1994) suggested that capuchins do not understand the causal relations involved in tool-using tasks; this may explain why the subjects in the current study performed so poorly. Most of the subjects did not seem to understand that the rods could be inserted into either end of the tube and that displacement of the reward was dependent upon the side of insertion of the rod. Furthermore, they did not seem to understand that once the reward was in the trap, reinserting the rod would not achieve anything. Had they understood these relations, they would not have had such strong insertion side biases and they would have paid more attention to the position of the reward in the tube.

It is interesting to note, however, that Garth did not have an insertion side bias and that across the last block of trials, he looked at the reward before working on the task on every trial. The fact that Garth looked at the reward before working suggests that he might have recognized that there was some importance in the reward's position relative to the trap, or to the end of the tube, but his poor performance on the task suggests that he never fully understood what the relation was. Although Garth did not perform above chance, even across the extra 30 trials, he did on six occasions remove partially inserted tools from the incorrect side of the tube and reinsert them into the correct side of the tube to dislodge the reward (as opposed to only one removal on the correct side of the tube with reinsertion into the incorrect side). Consistent with his behavior on this task, Garth was also the only subject in Experiment 3 who never attempted to insert unmodified tools across the last block of trials, suggesting he came to understand the relevance of modifying the pipes in order to use them. Therefore, it would be interesting to see if Garth's performance improved if he were given the opportunity to complete 140 trials as were given to the subjects in Visalberghi and Limongelli's (1994) study.

In sum, the results from this experiment are inconclusive concerning the effects that manipulative experience with the materials used in a task have on performance of that task. Social factors may have interfered with the experience group subjects' performance on this task. Additionally, the inappropriateness of the manipulative experience provided may have contributed to the lack of performance differences between the groups. However, an alternative possibility, which will be discussed in more detail in Chapter 7, is that this task was too complex for the capuchins. Future investigation of the effects of experience on trap-tube task performance should provide a different type of experience that might facilitate learning about the function of a trap.

Chapter 6

Discussion I.

Experience and capuchin tool-using ability

This chapter will discuss three interpretations that might explain the effects that manipulative experience had on the capuchins' performance in Experiments 1 and 3. One of these interpretations, including its predictions for other aspects of capuchins' tool-using abilities will be tested experimentally. Finally, implications for comparative studies on tool-using ability will be addressed.

Effects of Experience on Tool Use: Some Interpretations

The results from Experiments 1 and 3 showed that experience with the task objects had some beneficial influence on capuchins' performance on these tool-using tasks. There are a number of ways in which these effects can be explained and this section will discuss three interpretations of the data.

Object curiosity

The simplest explanation for the capuchins' enhanced performance from experience with the objects used in the tasks is that this experience reduces the distraction of capuchins' curiosity towards the objects. Capuchin monkeys are known for their curiosity and active exploration of objects, and certainly novel objects should provoke much curiosity from them. Therefore, one possibility is that prior experience provides capuchins with an opportunity to explore the objects and thus get beyond their initial curiosity. If experience had this function in the first task, then the prediction is that the non-experienced capuchins would exhibit a higher level of curiosity at the start of testing, and manipulate the objects more frequently, exploring the various behaviors that could be performed with them. The capuchins with manipulative experience, on the other hand, would not manipulate the objects with as high a frequency, nor perform the complete repertoire of behaviors possible with them - because they would already have done so during manipulative sessions. Thus, the experienced capuchins would approach the task in a less exploratory manner at the start of testing, so working more efficiently. This interpretation could also explain how both groups of monkeys might arrive at their first solution of the task at the same time, although for very different reasons. Whereas the non-experienced capuchins may have arrived at solution through their higher frequency of object manipulation at the start of testing, the experienced capuchins would have arrived at solution as a result of their overall experience with manipulating the objects during manipulative sessions, relating it to the demands of the task at the start of testing.

The data, however, do not concur with the prediction: although both groups of monkeys discovered how to dislodge the reward at the same time, the non-experienced monkeys did not manipulate the objects more frequently than did the experienced monkeys. In fact, the experienced capuchins made more attempts to dislodge the reward before initial solution than did the non-experienced capuchins. Therefore, this interpretation of object curiosity fails to explain the results.

Social learning

Another possible interpretation of the capuchins' enhanced performance on these tasks is that it was influenced by observing other subjects manipulating the objects or solving the task. By watching conspecifics, subjects could potentially learn something about the behavior necessary to solve the task or the relations between the objects involved in solving the task. Subjects could also be more likely to perform manipulations, or to direct attention towards the objects used in the task, thus increasing their probability of learning how to solve the task on their own. In either case, the capuchins' performance could potentially be enhanced, either directly or indirectly, through being housed and tested socially and thus having the opportunity to observe conspecifics. The problem with this is that if social learning had taken place, it could reduce the effective sample size of each group. If so, a general difference between individuals in two groups might be a consequence of a single individual's success in one group, followed by social learning by the rest of the group, rather than a true effect of the difference in the groups' manipulative experiences.

There are four main categories of social learning that may have played a role in subjects' performance on these tasks: imitation, emulation, social facilitation, and stimulus enhancement. *Imitation*, as defined by Beck (1976; 1980), Tomasello, Davis-Dasilva, Camak, and Bard (1987), and Visalberghi and Fragaszy (1990), is the topographical replication of a novel behavior by an observer without trial and error. *Emulation*, as defined by Tomasello (1990) and Whiten and Ham (1992, 'goal emulation') is the reproduction by an observer of the same goal achieved by the demonstrator. Unlike imitation, however, individual learning or prior knowledge is responsible for the observer's means of reaching the goal. *Social facilitation*, as defined by Spence (1937) and used by Beck (1976; 1980), Tomasello et al. (1987), and Visalberghi and Fragaszy (1990), is the increased probability of performing a behavior, or class or behaviors, already within the observers' repertoire, when a conspecific performs the same behavior, or class of behaviors. It is important to note that social facilitation cannot be latent; the observer must perform the behaviors at approximately the same time as the demonstrator. *Stimulus enhancement*, as defined by Spence (1937) and Thorpe (1956) and used by Beck (1976; 1980), Tomasello et al. (1987), and Visalberghi and Fragaszy (1990), is the increased probability of orienting behavior towards particular stimuli that a conspecific's behavior is oriented towards.

Of the four types of social learning, imitation is the only one in which the goal can be achieved without trial and error learning on the part of the observer. For the other three, the saliency of a particular goal, behavior, or stimuli is increased, but this does not directly provide the observer with the information necessary to achieve the goal. Therefore, the probability that an observer will learn to solve a task on their own may be increased if their attention is drawn to particular features of the task (the goal, behavior, or objects), however individual learning is still necessary on the part of the observer to achieve solution. These are important distinctions to make when considering the influence social learning may have on the performance of the capuchins in these tasks. It is also important to recognize the potential for most of these mechanisms to operate under conditions where subjects are tested socially. This section will discuss each of these potential influences, how they might explain the group differences found in these tasks, and whether the data support these explanations.

Imitation

Because there was no evidence for imitation in these tasks (see Experiment 1, Chapter 2, and Experiment 3, Chapter 4), there is no reason to presume that statistical analysis of the subjects as independent was invalid due to imitation. This lack of evidence for imitation is consistent with the lack of evidence from previous studies of capuchins and other monkeys (see Visalberghi & Fragaszy, 1990, and Whiten & Ham, 1992, for reviews). Just in case, though, it is worth looking at the results that would be predicted by such an influence.

If imitation took place in these tasks, the following prediction could be made: subjects in either group that observed another individual solve the task would achieve solution rapidly, replicating the solution behavior of the demonstrator. Crucially, if a subject in one group achieved solution earlier than subjects in the other group, then other subjects in its group would also solve the task more rapidly. Additionally, if a subject in one group developed a more efficient method for solving the task, evidenced by fewer errors and inefficient behaviors or a more effective modification technique, then other individuals in its group would also solve the task more efficiently.

Emulation

Although there is no evidence for emulation in monkeys (see Visalberghi & Fragaszy, 1990, and Whiten & Ham, 1992, for reviews), if emulation did have an effect on the capuchins' performance in these tasks then the following prediction could be made. During test sessions, subjects would be more likely to reproduce the goal of acquiring the reward lodged inside the tube as a result of observing other individuals achieving the same goal. Most importantly, if a subject in one group happened to achieve the goal early, then others in its group might also solve the task quickly.

Social facilitation

Because social facilitation has been suggested as a possible influence on the dissemination of behaviors among monkeys in previous studies (Visalberghi & Fragaszy, 1990; Whiten & Ham, 1992), it also possible that it played a role in these experiments. If social facilitation had an effect on the capuchins' performance in these tasks, then the following prediction could be made. During test sessions, subjects that worked on the task in the presence of conspecifics would have had an increased frequency of manipulation when conspecifics manipulated at the same time. Crucially, if one individual happened to be much more manipulative, and especially if this individual achieved a rapid solution, the others in its group should show increased manipulation and/or more rapid solution.

We must remember, though, that according to the definition of social facilitation the observer would not show elevated behavioral interactions with the test objects, in particular; they would simply be more likely to perform manipulations with any objects in their environment because they saw others doing the same. Therefore, the opportunity to observe other subjects manipulating objects may not be a sufficient condition for learning how they work. An additional factor may influence the capuchins' performance on these tasks.

Stimulus enhancement

Stimulus enhancement has previously been recognized among capuchins and other monkeys (Adams-Curtis & Fragaszy, 1995; Beck, 1973; Visalberghi & Fragaszy, 1990; Zuberbühler, Gygax, Harley, & Kummer, 1996), and is thus likely to have had an influence in these tasks. If stimulus enhancement played a role in the capuchins' performance, then the following prediction could be made. During test sessions, subjects would have had an increased frequency of attention, possibly in the form of manipulation, towards the task objects as a result of other individuals in their group manipulating those objects. Most importantly, if one subject happened to pay more attention to the task, or manipulate the task objects more frequently, and particularly if this individual achieved a rapid solution, the other subjects in its group should display increased attention towards the task objects and/or more rapid solution.

Evidence for social learning?

The data do not support the social learning predictions. The most rapid solution in Experiment 1 was made by a subject in the non-experience group, yet no group level advantage emerged for this group. They did not learn how to solve the task any earlier, nor complete subsequent trials more quickly than the experience group. In Experiment 3, the first subject to reliably modify tools was also in the non-experience group. Further, he manipulated the objects and directed attention towards them for longer periods of time during test sessions, but no group level advantage emerged for the non-experience group in this experiment either.

Whereas the first subject in each experiment to solve the task or reliably modify the tool was in the non-experience group, the subject to demonstrate what appeared to be the most efficient strategy for modifying tools in Experiment 3 was a member of the experience group. However, he was not the first to use this technique during test sessions despite using it to modify tools during manipulative sessions. The first subject to use this strategy during test sessions only did so after having modified the tool inadvertently in a very similar fashion on previous trials (see Chapter 4). Therefore, both subjects had previous experience modifying the tools in that manner before their strategies emerged as reliable during test sessions.

The data, therefore, do no support the results predicted by social learning influences. It is unlikely that imitation, emulation, social facilitation, or stimulus enhancement were responsible for the group differences found in these tasks.

Affordance learning

There is one last interpretation of the beneficial effects of object experience on capuchin's tool-using performance that is also consistent with the details of the data. This is that manipulative experience with task objects provides capuchins with the opportunity to learn about the affordances, or the functional properties, of those objects both in general and in specific relation to the task (Gibson, 1977; Greeno, 1994). That is, capuchins with experience have a better idea of how the objects can be used, or what behaviors could be performed with them, from their *general* exploration of those objects before they approach the task. Then, once the demands of the task have become clear, this occurring when a reward is present, the experienced capuchins further explore the function of the objects as tools in *specific* relation to the task, or how the tools can be used with the task in order to obtain the reward, and thus narrow the repertoire of manipulations they perform with the objects during subsequent testing. If manipulative experience had this effect during the tasks, then three predictions would follow about the capuchins' performance.

First, compared to the non-experienced capuchins, the capuchins with experience would manipulate the objects more frequently at the start of testing in the first experiment. This is because the experienced capuchins would already have developed a manipulative repertoire with the objects during initial manipulative sessions. However, they would not *necessarily* learn to dislodge the reward before the non-experienced capuchins because they were not made aware of the task demands any earlier, since they were not introduced to the specific goal of the task during manipulative sessions. Thus, although the experienced monkeys have developed a manipulative repertoire with the objects, they have no more appreciation for the appropriate use of the objects as tools for solving the task than do the non-experienced monkeys. Data from the first experiment concur with these predictions: compared to the non-experienced capuchins, the experienced capuchins did manipulate the objects more frequently at the start of testing; that is, they made more attempts to dislodge the reward before their initial solution. Additionally, both groups of capuchins learned to push a rod through the tube to dislodge the reward, thus solving the task, at the same time.

Second, during the manipulative sessions occurring *after* the capuchins' first solution of the first task, their object manipulations would become more goal-oriented. In other words, once aware of the task goal and how to realize that goal, the capuchins' manipulation of the task objects would become more focused on exploring those behaviors that are specific to dislodging the rewards. Data from the first experiment concur with this prediction: the experienced capuchins increased their frequency of tool contacts with the tube and also began inserting the rods into the tube during the manipulative sessions that occurred after their first solution of the task.

The third prediction, if manipulative experience facilitates appreciation of the task-objects' affordances, is that after learning how to dislodge the reward, the capuchins with manipulative experience would exhibit more efficient performance on the tasks. This is because their exploration of the specific affordances of the objects in relation to the tasks would enable them to narrow their manipulative repertoire with the objects during testing to a smaller subset of manipulations oriented towards realizing the task goal. By narrowing their repertoire of manipulations, the experienced capuchins are, in effect, decreasing their performance of errors and inefficient behaviors across trials. In contrast, the non-experienced capuchins would not perform with the same level of efficiency on the tasks because they have not had a chance to explore the objects' affordances and thus would still perform a wide variety of behaviors not beneficial to successful solution of the tasks. Data from the experiments do concur with this prediction: experienced capuchins worked more efficiently on the tasks. In both experiments they successfully completed the trials more quickly than did the non-experienced capuchins and in Experiment 3 they decreased their trial completion times across trials. The experienced monkeys also discarded fewer tools and stopped working on the task mid-trial less frequently than did the non-experienced subjects, in addition to decreasing their performance of these behaviors across trials. Lastly, in Experiment 3, the experienced subjects decreased their frequency of attempts to insert unmodified tools into the tube across trials.

Conclusions and implications

The experienced capuchins' higher frequency of object manipulations before their first solution is most consistent with the interpretation that manipulative experience with task objects provides an opportunity for exploration of their general affordances before the demands of the task are realized. Additionally, the improvement in performance of the capuchins with manipulative experience, as well as their more efficient performance compared to that of the non-experienced monkeys, is consistent with the interpretation that experience with task objects provides an opportunity for exploration of their specific affordances in relation to the task, once the task demands are clear. In other words, initial exploration of the objects, before being presented with the baited task, allows capuchins to explore all of the manipulations that can be performed with the objects themselves and in combination with other objects. Then, once the goal of the task is known, manipulating the task objects allows capuchins to explore manipulations with the objects that are effective for solving the task, and the consequences of those manipulations. Therefore, this interpretation appears to be the best explanation for the direct effects of experience on the capuchins' performance in these tool-using tasks. This agrees with Schiller's (1957) finding that non-socially tested chimpanzees who manipulated sticks were the ones who later used sticks properly to solve a raking task. It is also consistent with Jackson's (1942) finding that a non-socially tested chimpanzee who could not solve a raking task, did so immediately after having had the opportunity to manipulate a stick without reward.

However, there remains one result not accounted for by these explanations; the capuchins with manipulative experience did not make any fewer errors overall than did the non-experienced capuchins. This is difficult to explain because error performance should correlate with efficiency, and compared to the non-experienced capuchins, the experienced capuchins both worked more efficiently on the tasks and improved their efficiency across trials. There are two possibilities for why the performance of errors was not affected by manipulative experience in these tasks. First, the errors may not have had enough influence on the outcome of the task because they only slightly delayed solution. For example, when a monkey tried to insert an unmodified pipe into the tube, that monkey only had to modify the pipe and try again. Similarly, when a monkey only partially inserted a pipe into the tube, without pushing the reward all the way to the end of the tube, that monkey only had to give the pipe another push to solve the task. These are minor delays in comparison to some of the possible inefficient behaviors which delayed solution for much longer periods of time. For example, when a monkey discarded a tool by throwing it to the back of their cage, solution of the task was delayed until the monkey retrieved the object. Similarly, when a monkey stopped working on the task mid-trial and left the apparatus to engage in another activity, such as grooming or eating, solution was delayed until the monkey returned to the apparatus and continued working. (Of course if the monkey never returned, the trial eventually ended without solution.) Therefore, inefficient behaviors had more control over the outcome of the task, if only by delaying it for a longer period of time, and this perhaps explains why the experienced capuchins' performance differed from that of the non-experienced capuchins' performance of inefficient behaviors and not of errors. Unfortunately, the trap-tube task did not shed further light on this issue and so this interpretation remains for future testing.

A second possibility for why there were no differences in frequency of errors between the groups is that causal understanding of the task was required for error-free performance. In other words, an understanding is needed of how the reward is displaced by the tool when the tool is inserted into the tube, and thus why the tool must be modified before insertion, or be pushed a certain distance through the tube to dislodge the reward. Capuchins, perhaps, do not have a full understanding of the causal relations between the task objects, and learning to appreciate their affordances during manipulative sessions does not enhance this. Manipulative experience may help the capuchins associate the tool objects with the task, and therefore decrease their tool discards and increase their persistence in working on the task. They may even decrease their frequency of errors across trials. But their success on the task may only be due to associative processes and not comprehension of the physical principles that affect success (Visalberghi et al. 1995). Without a more complete understanding of the specific cause-effect relations involved in the task, it is possible that the experienced capuchins will make as many errors as the non-experienced capuchins while working on the task.

In sum, the interpretation that capuchins learn to appreciate the affordances of task objects through exploration of them during manipulative sessions still seems to be the best explanation for the effects that experience had on the capuchins' performance during the tool-using tasks. Perhaps future research will elaborate why error performance was not affected by the experience; whether it was a lack of influence on the outcome of the task, or a lack of causal understanding of the task by the capuchins. In any case, the results of these experiments have some interesting implications for capuchins' problem-solving abilities. It seems that capuchins are capable of learning the affordances of objects as tools, and this suggests that they can, therefore, appreciate differences between objects which allow them to function in different ways. Additionally, it suggests that capuchins can be flexible in their use of objects, using them both in specific relation to the task (as a tool to obtain a goal) and for more general manipulation. The fact that the monkeys rarely inserted non-tool objects or 'T' caps into the tube, and that two of them learned to modify 'T' capped pipes before attempting to use them, is consistent with the idea that capuchins can appreciate differences between the objects and the ways in which they function.

Further support for capuchins' ability to appreciate differences between objects in their appropriateness as tools comes from Anderson and Henneman's (1994) study in which one capuchin monkey both systematically chose the appropriate tool for solving a task, and almost exclusively used an adequately modified tool for repeated bouts on a task instead of abandoning the tool in favor of less adequate ones, as had been found by Visalberghi and Trinca (1989). Westergaard and Fragaszy's (1987b) study also supports the idea that capuchins can appreciate the relevant characteristics for a tool to be used in a specific task. Subjects in their study were observed to spontaneously enter an indoor cage out of visual range of the apparatus set up in an outdoor cage, manufacture probing tools by detaching sticks from branches and subtracting projections from the sticks, or select sponging materials (paper towels, browse, or straw), and transport them directly to the apparatus in the outdoor cage. Westergaard et al. (1998) also observed pre-use modification of probing tools by capuchin monkeys. Additional support for this ability in New World monkeys comes from Hauser (1997) who investigated cotton-top tamarins' tool preferences for raking in food rewards. He found that tamarins exhibit clear preferences for functional rather than non-functional tools, despite changes in their irrelevant characteristics such as color and texture. Thus, the results suggested that tamarins could distinguish between the relevant (shape and size) and irrelevant (color and texture) properties of tools, and that the distinction was based on functionality of the tool.

In contrast, Visalberghi and Trinca (1989) found that capuchins did not modify tools appropriately before attempting to solve the tube task and persisted in using inappropriate objects when appropriate objects for dislodging the reward were available. These behaviors suggested a lack of appreciation of the properties required for a tool to be effective. Further, Visalberghi et al. (1995) interpreted capuchins' persistence in performing errors on the complex conditions of the tube task ('H' shaped sticks, short sticks, and bundle) as evidence that they view the sticks, and other objects, as "magical wands" which make treats appear, and do not understand that the sticks must possess certain characteristics in order to dislodge the reward. Thus, Visalberghi and colleagues argue that "capuchins know that a tool is needed, but that they do not know what features allow one object to fit into the tube and displace the reward and what causes another to be ineffective" (Visalberghi & Limongelli, 1996; p.73).

To shed further light on this controversy over whether capuchins are capable of appreciating the characteristics of objects which allow them to function appropriately as tools, the next two sections will present brief experiments, with the experienced subjects used in Experiments 1 - 4, which investigated this ability. Specifically, the ability to appreciate different functional characteristics of objects was examined by analyzing one subjects' short pipe manipulations (see Chapter 3 for details on Garth's pipe connections) and by investigating object choices made by the capuchins when presented with a choice between appropriate and inappropriate objects to use as tools for solving a task.

Experiment 5: Appreciation of Functional Differences Between Objects I

This experiment examined the object manipulations of one experienced group subject who had connected short pipes together during Experiment 2 (see Chapter 3). Just after completion of Experiment 2, Garth was provided with the short pipes used in that experiment and his manipulations were recorded on video. There were two ways to line up the ends of pipes: (1) the connector end of one pipe with the plain end of the other pipe, thus connecting the objects together because the plain end fits into the connector, or (2) the plain ends of both pipes, thus failing to connect the objects because neither end fits into the other (see Figure 6.1). By systematically manipulating the pipes, alternating the ends at which they are lined up, successful connection of them 50% of the time can be achieved. However, rates of success significantly higher than this level require a distinction to be made between the different ends of the pipes, as well as an appreciation for which ends fit into one another. It was hypothesized that if Garth appreciated how to properly fit the objects together, he would line up the appropriate ends of the pipes significantly more often than he would line up the inappropriate ends of the pipes when he attempted to connect them. Thus, Garth's behavior was assessed for evidence of an appreciation for the appropriate way to connect the objects together, as opposed to inadvertently connecting them through persistent manipulation.

Method

Subject and materials

Garth was one of the experience group subjects already used in Experiments 1 and 2 (and later used in Experiments 3 and 4), and was the only subject who connected pipes regularly throughout the manipulative sessions in Experiment 2 (see Figure 6.2). His housing (including the designated "test" cage), diet, and provision of enrichment objects remained the same as in the previous experiments. The objects provided were two of the pipes used in Experiment 2 (Figure 6.1). One pipe had a connector piece fitted on one end and nothing on the other end. The second pipe did not have anything on either end. The plain ends of the second pipe fit into the connector piece on the first pipe. A video camera was used to record the sessions.

Procedure

Garth was separated into the test cage with one non-subject cagemate. The two pipes were provided. Garth's object manipulations were

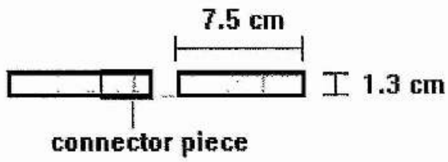


Figure 6.1. Two pipes, one with a connector piece. Dotted lines show how one pipe fits into the connector on the other pipe.

Figure 6.2. Garth connects two pipes together during a play session in Experiment 2.

recorded for a total of seven minutes across two sessions. The taped sessions were coded for each bout of pipe connection made. A bout began when Garth first picked up the pipes after having put them down on the perch, and ended when Garth put them down on the perch again after having manipulated them. For each bout, the first attempt to connect the pipes together, or the first time Garth lined up the pipes and touched their ends together, was scored as either a correct or an incorrect attempt. A correct attempt was one in which the pipes were lined up such that the end of one pipe was fitted into the connector piece of the other pipe. An incorrect attempt was one in which the plain ends of both pipes were lined up together, thus failing to make a connection. Only Garth's first attempt to connect the objects in each bout was scored to ensure independence between data points, and because it was believed to reflect his appreciation of the problem most clearly. On subsequent attempts, he could have inadvertently connected the pipes together through persistent manipulation influenced by a first unsuccessful attempt. Thirty bouts were scored.

Results and Discussion

Garth successfully connected the pipes together on 27 out of 30 opportunities. On the other three, he incorrectly lined up the ends of the pipes and thus did not connect them. Garth's frequency of successful pipe connections was significantly above that expected from chance performance (binomial test, N=30, p<.001). The three times in which Garth incorrectly lined up the pipes on his first attempt of the bout occurred on bouts 25, 26, and 30. Garth immediately corrected his orientation of the pipes to one another and connected them together on the next attempt. Although it could be argued that these connections which occurred on Garth's second attempt in the bout may simply have been inadvertently due to his persistent manipulation of the pipes after an incorrect attempt, this seems less likely to have been the case when it is recalled that these bouts occurred after 24 correct pipe connections on the first attempt. Garth's performance, therefore, suggests that he has an appreciation of the appropriate characteristics necessary for the ends of each pipe in order to properly fit them together. His success with the pipe connections was not inadvertently due to persistent manipulation of the objects on each bout. Whether Garth learned the association between the appropriate ends of the pipes and their capacity for connection during his manipulations in Experiment 2, or whether he had a prior understanding of how smaller pipes fit into larger ones is not clear. However, it is certain that he can distinguish subtle differences in the characteristics of the objects that allow them to be combined.

Experiment 6: Appreciation of Functional Differences Between Objects II

This experiment assessed whether the experienced capuchins could appreciate the characteristics that make an object appropriate for solving a particular task. Specifically, the abilities of the capuchins to choose the correct object for solving the task used in the first experiment were investigated. Two conditions were presented to the capuchins (just after completion of Experiment 5, prior to Experiments 3 and 4). In the first condition, subjects were given a choice between two familiar objects. One, the correct tool for solving the task, was the rod used in Experiment 1. The other object was a stone, similar to ones used by some of the subjects for cracking open nuts or cutting through plastic in previous experiments (Westergaard et al., 1997; Westergaard & Suomi, 1993a). In the second condition, subjects were given a choice between the familiar stone and an unfamiliar pipe which had the necessary characteristics for solving the task. The familiar rod and unfamiliar pipe were distinguishable by three characteristics unrelated to the task: color, hardness, and whether or not the ends were sealed. It was hypothesized that if the capuchins appreciated the characteristics which made an object appropriate for solving the task, they would chose the correct object significantly more often than they would chose the incorrect object for solving the task in both conditions.

Method

Subjects and materials

The subjects were the four experienced group capuchins already used in Experiments 1 and 2 (and three of whom were later used in Experiments 3 and 4). Their housing (including the designated "test" cage), diet, and provision of enrichment objects remained the same as in the previous experiments. The apparatus was the same as that used in Experiments 1 through 3: that is, a transparent plastic tube (30 cm in length and 2.4 cm in diameter) mounted in a frame (see Chapter 2). Three objects were provided to be selected for use as tools (see Figure 6.3): the correct, familiar object was a white, durable plastic rod created by placing caps on either end of a pipe (30 cm in length and 1.3 cm in diameter); the correct, unfamiliar object was a black, plastic pipe (30 cm in length and 1.3 cm in diameter) made from a softer plastic than the white rod; and the incorrect, familiar object was a stone (approximately 3.8 cm in length and 2.5 cm in diameter at its widest point). A rolling, metal cart was used to present the objects to the capuchins so that the objects could be laid out before each trial, presented to the subject, and then quickly removed as soon as a choice was made - that is, as soon as one object was removed from the cart and before the other object could be touched. The non-experienced capuchins were not tested on this task because their cage set-up did not allow for use of the metal cart.

Procedure

The apparatus was set up inside the test cage and baited as was done in Experiment 1. Each subject was separated from the group for testing, typically with a non-subject companion. Two objects were placed on the metal cart out of subject's view, randomly switching the side of placement of each object. In the first condition, the white rod and the stone were placed on the cart. In the second condition, the black pipe and the stone were placed on the cart. A trial began when the cart was placed within subject's reach. The trial ended when the subject removed an object from the cart. The cart was removed from subjects' reach as soon as the trial ended. Two bouts of ten trials were given to each subject for each condition. The conditions were alternated such that one bout of the first condition was given followed by one bout of the second condition, and then the sequence was repeated. Subjects' object choices were recorded for each trial.

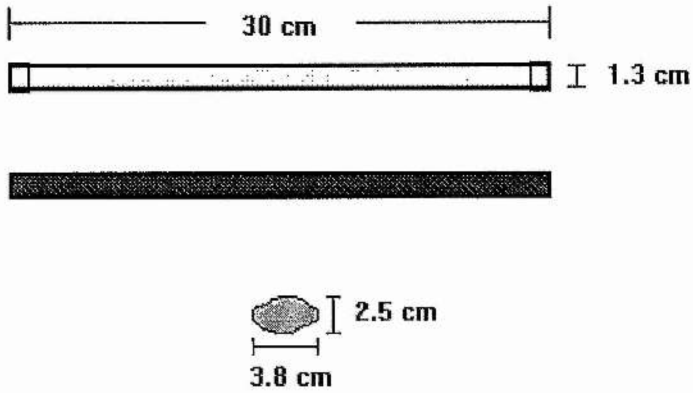


Figure 6.3. Familiar, plastic rod; unfamiliar, black pipe; and familiar stone.

Results and Discussion

In the first condition, familiar rod versus familiar stone, all four subjects chose the correct object on 100% of the trials. Their frequencies of correct choices were significantly above that expected from chance selection (binomial test, N=20, p<.0001). In the second condition, unfamiliar pipe versus familiar stone, three subjects (Garth, Java, and Jesse) again chose the correct object on 100% of the trials, significantly above that expected from chance selection (binomial test, N=20, p<.0001; Figure 6.4). One subject, Zephyr, chose the correct object on 90% (18 out of 20) of the trials. Zephyr's frequency of correct choices was still above that expected from chance selection (binomial test, N=20, p<.001). Zephyr's incorrect object choices in the second condition occurred on the first trial, the first time Zephyr had been exposed to the unfamiliar black pipe, and again on the fourth trial. On the first trial, Zephyr unsuccessfully attempted to insert the stone into the tube and then unsuccessfully attempted to insert a piece of chow into the tube by banging it against the end of the tube with the stone, before abandoning the task altogether. On the fourth trial, Zephyr first chose the stone and banged it against the middle of the tube, without attempting to insert it. He then went back to the cart, as it had mistakenly not been removed on this trial, and chose the black pipe and solved the task. On all other trials Zephyr chose the correct object for solving the task, suggesting that although he may not have recognized on the first trial that the unfamiliar pipe possessed the characteristics necessary for a tool needed to solve the task, he did learn to appreciate those characteristics after four trials. Certainly part of the capuchins' success at choosing the correct object could be due to learned associations between the familiar white rod and the tube task, but this does not explain why three of the four capuchins chose the correct, unfamiliar black pipe, instead of the familiar stone, on the first trial of the second condition, and continued to do so on every subsequent trial. Therefore, these results suggest that capuchins can appreciate the characteristics which make an object appropriate to be used as a tool for solving a particular task because they were able to chose the correct tool when forced to make a choice between familiar and unfamiliar tools, both appropriate and inappropriate for solving the task.

Figure 6.4. Garth reaches for the correct, but unfamiliar, pipe instead of the incorrect, familiar stone as the cart is being pushed towards his cage.

Implications for Comparative Studies

Results from the tool-using tasks presented in Experiments 1 - 4 suggested that capuchins are perhaps capable of appreciating the affordances of objects as tools, and the characteristic differences between objects which allow them to function differently. This was further investigated in Experiments 5 and 6, which supported the notion that capuchins can appreciate the properties required for objects to be effective as tools. The capuchins in those experiments showed an appreciation for how two pipes fit together, by repeatedly fitting the correct ends together, and of which characteristics are necessary for an object to be used as a tool to solve a task, by repeatedly choosing the correct objects when both familiar and unfamiliar objects were presented. Therefore, the current data supports claims made by Anderson and Henneman (1994), Westergaard and Fragaszy (1987b), and Westergaard et al. (1998) that some capuchins are capable of distinguishing functional characteristics of objects, and compare with Hauser's (1997) findings that another species of New World monkey (tamarin) has the same capability. It contradicts, however, previous claims by Visalberghi and colleagues (Visalberghi et al., 1995; Visalberghi & Trinca, 1989) based on research in which capuchins failed to appreciate the features of objects which allow them to be effective. It should be pointed out, though, that these abilities have only been shown by a subset of capuchins, and the subjects in the current studies which exhibited these abilities were those who had been provided opportunities to manipulate the task objects both before and during testing. The experienced monkeys were the ones who decreased their performance of errors, tool discards, and mid-trial work breaks across trials. They were also the subjects who modified tools efficiently and did so before attempting to use them. Therefore, it is this subset of capuchins who provided evidence for their ability to appreciate the affordances of objects as tools and the differences between the objects which allow them to function as tools in different tasks.

The fact that it was only the experienced capuchins who performed in this manner has important implications for comparative work which has been carried out to assess the differences in tool-using ability between monkeys and apes. Moreover, the studies by Visalberghi and colleagues (Limongelli et al., 1995; Visalberghi et al., 1995), which compared the performance of chimpanzees, bonobos, and an orangutan on tube and trap-tube tasks with that of capuchins previously tested on those tasks, may have been premature in interpreting the differences between capuchin and ape abilities. Whereas most of the apes were raised in, or extensively exposed to, human-like cultural environments, experienced with some form of language, and provided with the opportunity to manipulate human objects on a daily basis, the capuchins were housed under standard laboratory conditions, without the special language and object enrichment received by the apes. The enhancement of tool-using performance and appreciation of object affordances evidenced in the current research suggests that the special conditions to which the apes in Limongelli et al. (1995) and Visalberghi et al.'s (1995) studies were exposed would be expected to have enhanced their performance on tool-using tasks, and thus comparing performance between these apes and capuchins is unfair. To objectively assess the differences between capuchin and ape tool-using abilities, a comparison of subjects with similar object experience is necessary. Although the experienced capuchins in the current experiments were not raised in a human-like cultural environment, they were more experienced with objects, from their exposure to them during the manipulative sessions, than were the non-experienced capuchins. Thus, an attempt was made at comparing the performance of the experienced capuchins from the current studies with that of the apes from Visalberghi and colleagues' studies (Limongelli et al., 1995; Visalberghi et al., 1995) using the same tasks. This comparison will be discussed in Chapter 7.

Chapter 7

Discussion II.
Capuchin/chimpanzee comparison

Exposure to a human-like cultural environment, in addition to extensive interaction with tools and objects has been claimed to enhance the cognitive abilities, and thus the tool-using abilities, of great apes (Call & Tomasello, 1996; Tomasello & Call, 1997). Different experiential histories of monkeys and apes, therefore, should be taken into consideration when comparing species' performances on cognitive tasks. It may be unfair to draw conclusions about species differences in problem-solving abilities from a comparison of object- and language-experienced chimpanzees with monkeys who lack the same experience. This is exactly what Visalberghi and colleagues have done, however, by comparing capuchin and ape performance on a series of tube and trap-tube tasks (Limongelli et al., 1995; Visalberghi et al., 1995; Visalberghi & Limongelli, 1994; Visalberghi & Trinca, 1989). To objectively assess species differences in tool-using ability, comparison between subjects with similar experiential histories would be necessary. However, monkeys have yet to be raised in the same human-like cultural environment as the apes had been in Visalberghi and colleagues' studies, and typical laboratory apes not raised in a human-like cultural environment have yet to be tested on these tasks.

Experience with objects to be used in problem-solving tasks has also been found to facilitate chimpanzees' use of those objects as tools in the problem-solving situation (Birch, 1945; Jackson, 1942; Schiller, 1957; see also Chapters 2 and 4). It seems that the object-experienced chimpanzees have a greater understanding of the functions of the objects as tools from manipulating them in absence of a need to use them. Therefore, the experienced capuchins from the current series of experiments may provide a "fairer" comparison group against which to evaluate the chimpanzee data of Visalberghi and colleagues (Limongelli et al., 1995; Visalberghi et al., 1995). Whereas the non-experienced capuchins are relatively inexperienced with the task objects, these experienced capuchins, like the chimpanzees, have had experience manipulating the objects (or similar objects as may be the case for the chimpanzees) and have had the opportunity to explore their affordances. A comparison between the capuchins from the current series of experiments and the chimpanzees studied by Visalberghi et al. (1995) may shed further light on the differences in tool-using ability between *Cebus* and *Pan*, as well as on the issue of object experience and its influence on previous interpretations of species differences in tool-using ability (Limongelli et al., 1995; Visalberghi et al., 1995).

This chapter presents a comparative analysis of capuchin and chimpanzee tool-using ability on the task presented to the capuchins in Experiment 3 (see Chapter 4) in which a pipe had to be modified in order to be used as a tool to push food through a tube. Data on chimpanzees' performance was derived from a study by Visalberghi et al. (1995), which used essentially the same task. All of the chimpanzee and pygmy chimpanzee subjects, which will simply be referred to as chimpanzees throughout this chapter, had been either raised in or later exposed to a human-like cultural environment, including interaction with a variety of human tools and artifacts (Tomasello & Call, 1997). Most of the subjects had also received language training and had been tested on a variety of cognitive tasks involving human interactional training (Savage-Rumbaugh, 1986; Savage-Rumbaugh & Lewin, 1994). Therefore, the chimpanzees tested in these studies were most likely familiar with a wide variety of objects and experienced with using them in many different contexts.

In contrast, the capuchin subjects were typical laboratory monkeys, socially-housed and raised by their own mothers. They had not been exposed to a human-like cultural environment, and had only interacted with the enrichment objects in their cages (e.g. hard plastic or rubber balls, cups, pipes, and chains) on a daily basis. The only other objects they had manipulated were those provided during previous experimental testing, such as sticks, stones, paper towels, and PVC plumbing fixtures, for the purpose of eliciting tool-using behaviors (Byrne & Suomi, 1996; Byrne & Suomi, 1997; Westergaard, 1994). Three of the capuchins (the subjects in the experience condition) had been exposed to the pipes and tubes used in the experiment during unrewarded manipulative sessions which occurred both before and at intervals intermittent with testing (see Chapter 4) and therefore, they had had more experience manipulating these objects, or at least more exposure to them, than had the three subjects of the non-experience condition.

Background

Sources of data

Capuchins

The capuchin data were taken from Experiment 3 (see Chapter 4), in which six capuchins (three experienced and three non-experienced; see Table 7.1) had to modify pipes, by removing 'T' shaped caps from the ends, and then use them as tools in order to solve the task. Capuchin data from Visalberghi and colleagues' studies were not used for this comparison for two reasons: 1) Visalberghi and Trinca's (1989) capuchins were hand-reared, and thus would not have been a good control for the experienced capuchins because of their different experiential backgrounds, and 2) the placement of the apparatus and the testing procedure used for Visalberghi et al.'s (1995) capuchins were not consistent with that used in the other studies, or with the apes used in their study; the apparatus was set up outside the cage and the different conditions of the task were presented alternately during a bout of testing. All subjects had completed 50 trials on a simpler version of the tube task, which required them to push a rod through the tube to dislodge the reward (see Experiment 1, Chapter 2), and 25 trials on a version of the task requiring a different form of tool modification, which required them to push multiple pipes through the tube to dislodge the reward (see Experiment 2, Chapter 3) before this experiment. In addition, the experienced subjects had each completed 40 trials on the tube task in which they had to chose the correct object to use as a tool (see Experiment 6; Chapter 6) before this experiment. Three types of error potentially made while solving the task had been scored: (1) *unmodified-tool use* - the attempted insertion of an unmodified pipe; (2) *'T' cap use* - the attempted insertion of a 'T' cap after modification; and (3) *partially-modified-tool use* - the attempted insertion of the unmodified end of a pipe after the other end has been modified.

Table 7.1

Subject Information for Experiment 3 Species Comparison

Species / Group	Subject	Sex	Age (yrs)	Tool Experience[a,b]
Cebus Experience	Zephyr	M	18.7	1,2,4,5
	Jesse	F	5.2	1,5
	Garth	M	4.1	3,5
Non-experience	Creepshow	M	7.0	2,5
	Lee	F	5.3	2,5
	Iko	M	3.5	5,6
Pan[c]	Lana	F	20.0	5,7,8,9
	Austin	M	15.5	1,5,7,8,9
	Panzee	F	4.5	
	Matata	F	20.0	7
	Kanzi	M	9.5	3,10
	Panbanisha	F	4.5	

[a] Tool experience: 1)Sponging (Savage-Rumbaugh, 1986; Westergaard & Suomi, 1993a); 2)Nut cracking (Westergaard & Suomi, 1993b); 3)Cutting (Toth, Schick, Savage-Rumbaugh, Sevcik, & Rumbaugh, 1993; Westergaard et al., 1997); 4)Bimanual tube dipping (Westergaard & Suomi, 1994b); 5)Syrup or ant dipping (Savage-Rumbaugh, 1986; Westergaard et al., 1998; Westergaard et al., 1997; Westergaard & Suomi, 1994c; 1994g); 6)Raking (Byrne & Suomi, 1997); 7) Stick-tube task (mentioned in Visalberghi et al., 1995); 8)Unlocking (with keys; Savage-Rumbaugh, 1986); 9)Unscrewing (with a wrench; Savage-Rumbaugh, 1986); 10)Stone flaking (Toth et al., 1993)

[b] Panzee and Panbanisha were experienced with using tools, however they had not been involved in any formal testing (E. S. Savage-Rumbaugh, personal communication, June 26, 1998).

[c] (Visalberghi et al., 1995)

Chimpanzees

The chimpanzee data were taken from a study carried out by Visalberghi et al. (1995) in which ten apes (five common chimpanzees, four pygmy chimpanzees, and one orangutan) had to modify 'H' shaped sticks, by removing the transversals from the ends of the sticks, and use them as tools to push a reward out of the tube. Data from only six of the chimpanzees, three common chimpanzees (*Pan troglodytes*) and three pygmy chimpanzees (*Pan paniscus*) were used for the comparison (see Table 7.1). The data from four other apes (two common chimpanzees, one pygmy chimpanzee, and one orangutan) in that study were excluded from this comparison. The three chimpanzees had completed fewer than ten trials, and therefore their data could not be compared directly with those of the other chimpanzee subjects. The orangutan belongs to a different genus (*Pongo*), and was excluded to keep the current comparison to *Pan* versus *Cebus*. Note, however, that exclusion of the orangutan subject significantly affected the analysis, changing the significance of some of the results, and thus the results reported in this section differ from those reported by Visalberghi et al. (1995).

All of the chimpanzees had been captive born, except for Matata, and housed at Georgia State University's Language Research Center (Visalberghi et al., 1995). All had been experienced with using tools (Savage-Rumbaugh, 1986; Savage-Rumbaugh & Lewin, 1994), although Panzee and Panbanisha had no formal tool-task experience (E. S. Savage-Rumbaugh, personal communication, June 26, 1998), and Lana, Austin, and Matata had been experienced with tube tasks involving straight sticks for use as tools (Visalberghi et al., 1995). Each subject had completed between three and nine trials, not counting previous experience with similar tasks, on a simpler version of the tube task that required them to push a straight stick through the tube to dislodge the reward. They had also completed between three and five trials on a version of the task requiring a different form of tool modification, breaking apart a bundle of sticks to create a thinner tool for solving the task, before this experimental condition involving the modification of "H" shaped sticks (Visalberghi et al., 1995). The same three types of error potentially made while working on the task had been scored in Visalberghi et al.'s (1995) study, although they had been given different names: (1)

"attempted insertion of the tool as provided, in its H form"; (2) "insertion of one of the transverse sticks"; and (3) "following removal of one transverse stick, attempted insertion of the other (still blocked) end of the tool" (p.54).

Differences between the studies

Apparatus

The transparent, plastic tube (48 cm in length and 3.8 cm in diameter) that had been provided to the chimpanzees was larger than that which had been provided to the capuchins, but was otherwise identical (Visalberghi et al., 1995; see also Chapter 2). The chimpanzees' tube had been attached to a wooden frame, mounted on the wall. The object which had been provided to the chimpanzees for use as a tool was a wooden dowel (48 cm in length and 2 cm in diameter), with two smaller sticks (18.0 cm in length and approximately 0.7 cm in diameter) affixed transversally near each end (Visalberghi et al., 1995). Although these dowels with the transversals differed from the plastic pipes with 'T' caps on the ends which had been provided to the capuchins, the modification requirements of both the dowels and the pipes were essentially the same because both involved removing pieces from the ends of the objects which had prevented them from being inserted into the tube.

Procedure

The chimpanzees had completed ten trials (two blocks of five trials each) on the task, whereas the capuchins had completed 25 trials (five blocks of five trials each) on the task. Because different methods had been used for baiting the chimpanzees' apparatus, such as covering the subject's eyes with a blanket, distracting them, or having them leave the room, and because the tools had been placed away from the apparatus such that subjects had to retrieve them before solving the task, the chimpanzees were in different positions with respect to the apparatus at the start of each trial (Visalberghi et al., 1995). Trial completion time (or solution time) data could not be statistically compared between the capuchins and the chimpanzees because of these different starting positions. Whereas the capuchins' completion times reflect their latencies to dislodging the reward from the time at which they had begun to attend directly to the apparatus, the chimpanzees' completion times reflect time that had been spent retrieving tool objects or reentering the testing room, in addition to latencies to dislodging the reward from the point at which they had attended to the task. Therefore, the data from each species do not reflect the same measurements, and thus were not comparable.

Subject histories

The capuchins and chimpanzees differed with respect to their experiential histories. Whereas the chimpanzees had extensive experience manipulating a wide variety of objects in an enculturated environment, the capuchins had only ever been exposed to the limited variety of plastic and rubber enrichment toys in their cages and the limited array of tool objects provided during previous experimental tests (Byrne & Suomi, 1996; Byrne & Suomi, 1997; Westergaard, 1994). Therefore, the capuchins had not had the same breadth of experience with manipulating objects as had the chimpanzees. Because of these differences in the experiential histories of the capuchins and the chimpanzees, it may still be unfair to compare the capuchins' initial performance on a tool-using task with that of the chimpanzees. Although the experienced capuchins were provided the opportunity to explore the task objects, and thus increase their experience manipulating these objects directly related to the task, their resulting object experience may not be equivalent to the object experience of the chimpanzees. It is not possible to compare the quantities and qualities of each subject's experience. However, because the capuchins completed 25 trials on the task, it may be "fairer" to compare their final performance, or their last 10 trials, with that of the chimpanzees. After 15 trials on the task, the capuchins may be more similarly experienced to the chimpanzees with respect to manipulating the tool objects in that specific context. Therefore, comparisons between the capuchins and the chimpanzees were made for both the capuchins initial performance on the task, the first 10 trials, and their final performance on the task, their last 10 trials.

Analysis

Because the capuchins had completed 25 trials on the task, compared to the apes' ten, the capuchin data were analyzed in two ways. First, a comparison was made between the experienced and non-experienced capuchins' error frequencies using the data from all 25 trials. The three types of error analyzed in Experiment 3, unmodified-tool use, 'T' cap use, and partially-modified-tool use, were combined as total errors for this and subsequent comparisons with the chimpanzees. This is because two of the errors, 'T' cap use or insertion of transverse stick, and partially-modified-tool use or attempted insertion of still blocked end, had been infrequently performed by both capuchin and chimpanzee subjects, and because total errors had been used for previous comparisons made by Visalberghi et al. (1995). Comparison of total errors between the experienced and non-experienced capuchins was carried out using the Mann-Whitney U test to assess differences in performance between the groups. Analyses of each group's performance trends were carried out using the Page Test for Ordered Alternatives to assess improvement in performance across blocks of trials.

Second, comparisons of trial completion times and error frequencies were made between the capuchins' first two blocks of trials, trials 1-5 and 6-10, in order to assess their initial improvement on the task in comparison to that of the chimpanzees. The one-tailed Wilcoxon Signed Ranks test for small samples was used to assess completion time and error performance differences between the capuchins' first two blocks of trials, as well as between the chimpanzees' blocks of trials. One-tailed tests were used in accord with the apriori hypothesis that frequency of errors and completion time would decrease across blocks (see Visalberghi et al., 1995). Because the capuchin sample sizes (three subjects in each group) were insufficient to meet even the criterion of the Wilcoxon test for small samples (Siegel & Castellan, 1988), the two groups of capuchins were combined for the analyses.

To assess differences in error frequency between the experienced capuchins, non-experienced capuchins, and chimpanzees, two different comparisons were made: the capuchins' first two blocks of trials (trials 1-10) were compared with the chimpanzees' ten trials, and then the capuchins' last two blocks of trials (trials 16-25) were compared with the chimpanzees' ten trials. The two-tailed Kruskal-Wallis One-Way ANOVA (Siegel & Castellan, 1988) was used to analyze differences in error performance between the groups of subjects. The Kruskal-Wallis post hoc test was also used to determine which differences were significant. Trial completion times were not statistically compared between groups because, as was mentioned earlier, the capuchin and chimpanzee subjects were in different positions with respect to the apparatus at the start of each trial.

Results

Capuchins

Across all 25 trials

The capuchins in the non-experience group made a higher frequency of total errors than did the capuchins in the experience group, but the difference was not significant (mean frequency per subject per block = 16.9 for the non-experience group vs. 11.7 for the experience group; Mann-Whitney U test, U=3.0, ns; Figure 7.1). The experience group did, however, significantly decrease their frequency of total errors across blocks of trials, whereas the non-experience group did not (Page Test for Ordered Alternatives, L=159, p<.01 for the experience group; L=143.5, ns, for the non-experience group). Note that the experience group also dislodged rewards significantly more quickly than did the non-experience group, and decreased their trial completion times across trials (see Chapter 4).

Across trials 1-10

Altogether, the capuchins dislodged rewards more quickly in the second block of trials (trials 6-10) than they did in the first block of trials (trials 1-5), but the difference was not statistically significant (mean time per subject = 170.2 seconds for trials 6-10 vs. 298.6 seconds for trials 1-5; Wilcoxon Signed Ranks test, T(6)=18, p=.08; Figure 7.2). The capuchins did, however, make significantly fewer total errors in the second block of trials than in the first block of trials (mean frequency per subject = 16.5 for trials 6-10 vs. 27.2 for trials 1-5; T(6)=21, p<.05; Figure 7.3).

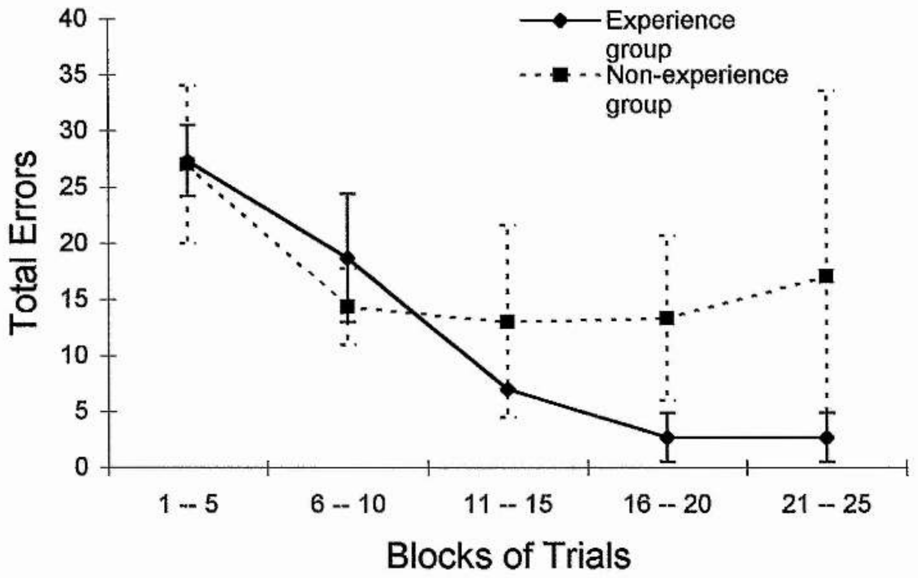


Figure 7.1. Frequency of total errors (±*SE*) per block averaged across subjects for each group.

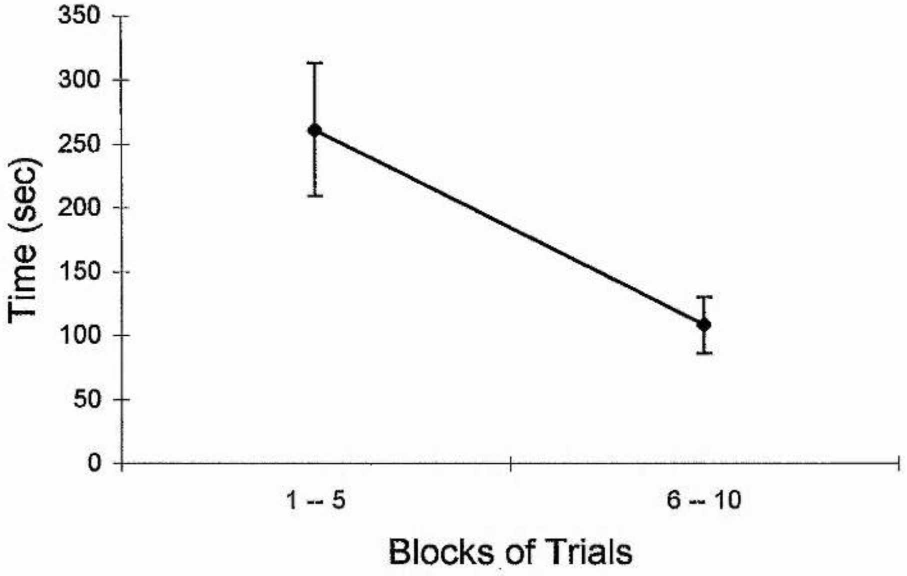


Figure 7.2. Capuchins' mean trial completion time (±*SE*) per block averaged across subjects for Blocks 1 and 2 (trials 1-5 & 6-10).

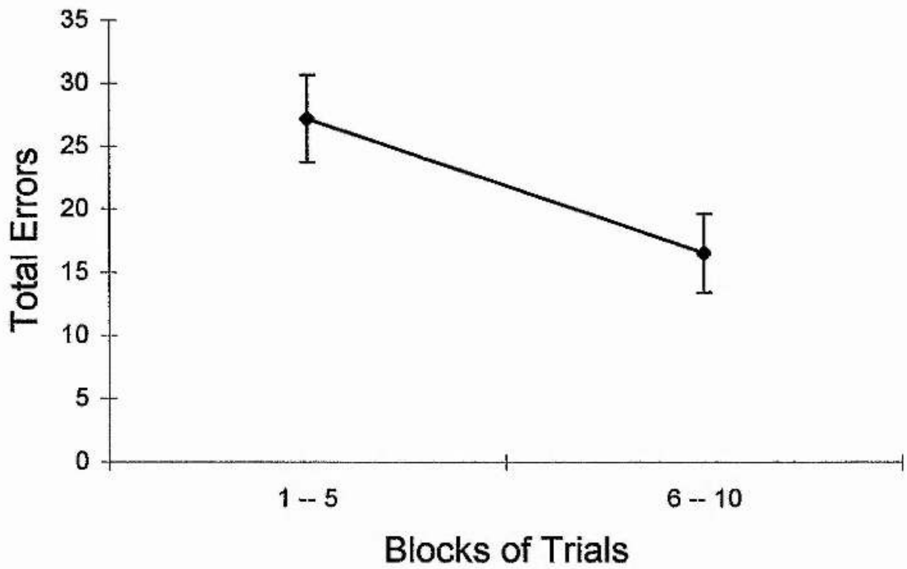


Figure 7.3. Capuchins' frequency of total errors (±*SE*) per block averaged across subjects for Blocks 1 and 2 (trials 1-5 & 6-10).

Chimpanzees

Although the chimpanzees dislodged rewards more quickly in the second block of trials (trials 6-10) than in the first block of trials (trials 1-5), the difference was not statistically significant (mean time per subject = 34.7 seconds for trials 6-10 vs. 60.9 seconds for trials 1-5; $T(6)=18$, $p=.08$; Figure 7.4). Note that this result differed from that reported by Visalberghi et al. (1995) due to the exclusion of the orangutan's data. Their reported statistic was $T(7)=25$, $p<.05$ (p.55.) Similarly, the chimpanzees' frequency of total errors decreased between the two blocks of trials, but the difference was not significant (mean frequency per subject = 4.7 for trials 1-5 vs. 1.5 for trials 6-10; $T(6)=16.5$, ns; Figure 7.5). Note that this result also differed from that reported by Visalberghi et al. (1995) due to the exclusion of the orangutan's data. Their reported statistic was $T(7)=23.5$, $p<.08$ (p.56.)

Species comparison

In order to assess more directly how the capuchins' performance differed from that of the chimpanzees both at the start of testing and after they had completed 15 trials, and thus gained more experience with the objects used in the task, two comparisons of total error frequency were made between the experience group capuchins, non-experience group capuchins, and chimpanzees.

Across the first ten trials the chimpanzees made fewer total errors than did either the experience group capuchins or the non-experience group capuchins (mean frequency per subject = 3.1 for the chimpanzees vs. 23.0 for the experience group and 20.7 for the non-experience group; Kruskal-Wallis One-Way ANOVA, $\chi^2(2, N=12)=8.32$, $p<.05$; Figure 7.6). Post hoc analyses revealed that although the chimpanzees made fewer errors than did either group of capuchins, the difference was significant ($p<.05$) between the chimpanzees and the experience group capuchins, but did not quite reach statistical significance ($p<.07$) with the non-experience group capuchins.

If instead the capuchins' last ten trials are compared with the chimpanzees' ten trials, both the chimpanzees and the experience group capuchins made fewer total errors than did the non-experience group

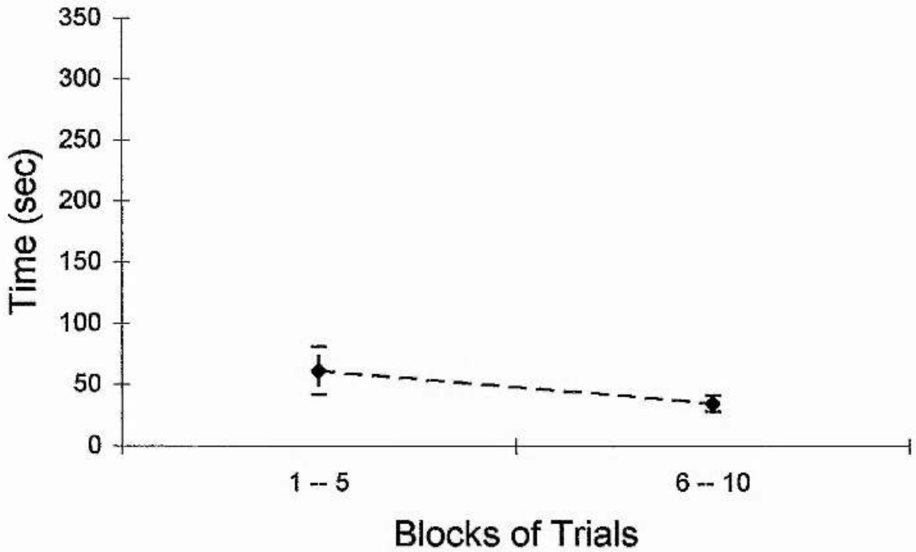


Figure 7.4. Chimpanzees' mean trial completion time (±*SE*) per block averaged across subjects (Visalberghi et al., 1995).

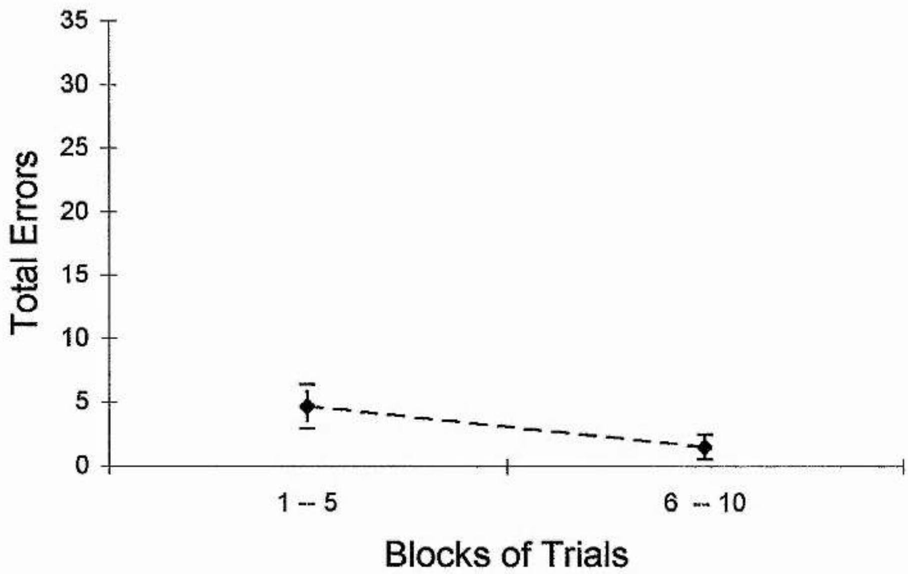


Figure 7.5. Chimpanzees' frequency of total errors (±*SE*) per block averaged across subjects (Visalberghi et al., 1995).

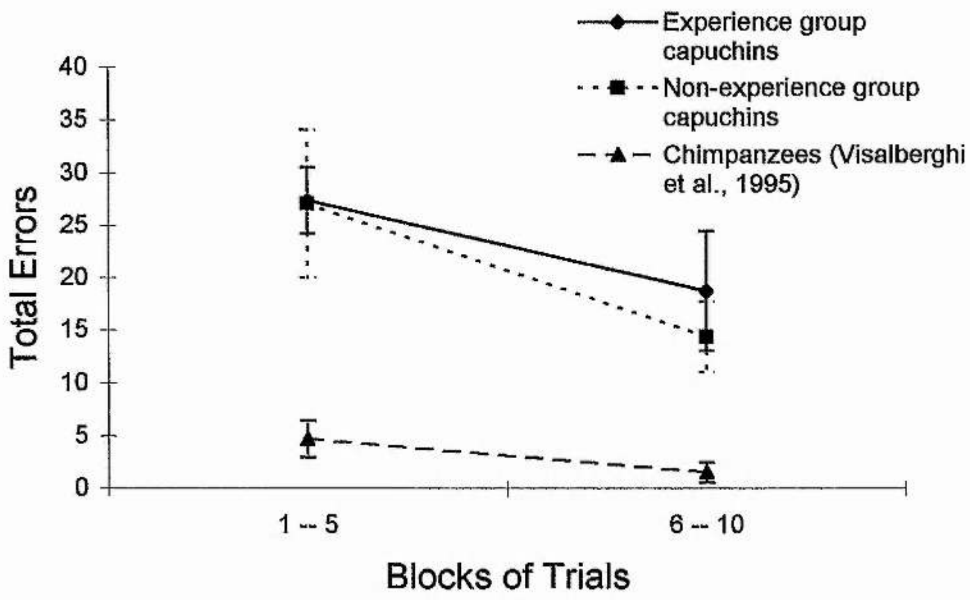


Figure 7.6. Frequency of total errors (±*SE*) per block averaged across subjects for each group. Capuchin data are for Blocks 1 and 2 (trials 1-5 & 6-10).

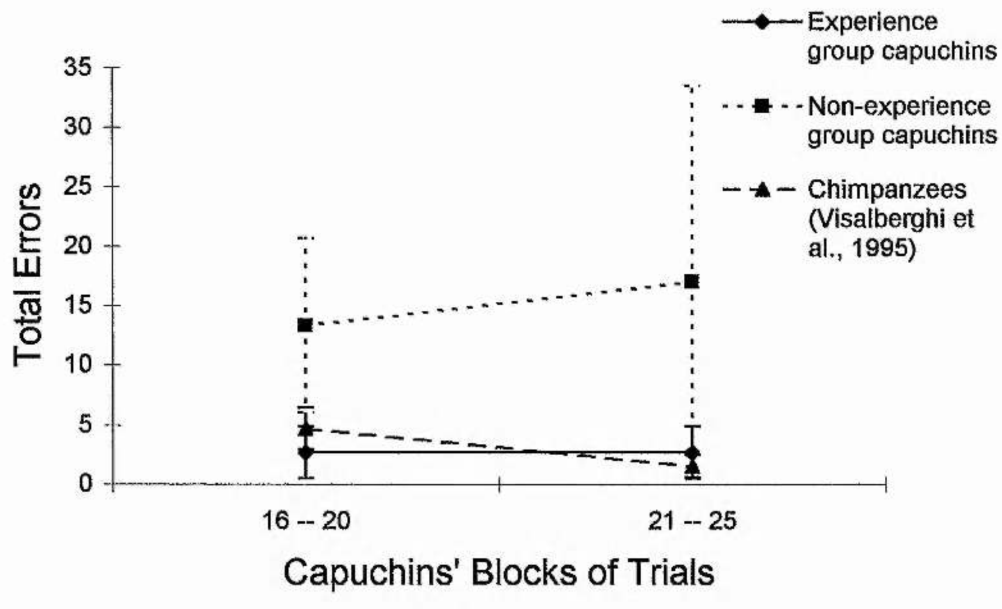


Figure 7.7. Frequency of total errors (±*SE*) per block averaged across subjects for each group. Capuchin data is for Blocks 4 and 5 (trials 16-20 & 21-25), whereas chimpanzee data is for Blocks 1 and 2 (trials 1-5 & trials 6-10).

capuchins, however differences between the groups were not significant (mean frequency per subject = 3.1 for the chimpanzees and 2.7 for the experience group capuchins vs. 15.2 for the non-experience group capuchins; $\chi^2(2, N=12)=1.34$, ns; Figure 7.7).

Discussion

Comparison of the capuchins' and chimpanzees' performances on this task has shown that although the chimpanzees made fewer errors on the task at the start of testing, the capuchins, particularly those with manipulative experience, improved their performance across trials and after having completed 15 trials, made as few errors as had the chimpanzees originally. The fact that the capuchins only needed 15 more trials than the chimpanzees to perform as few errors as they had on the task, combined with the fact that the experienced capuchins were the subjects that performed most similarly to the chimpanzees, suggests that experience with the task materials may be an important influence on tool-using ability. It is not possible to quantify the experiential histories of the subjects, but it is likely that the chimpanzees' object manipulation experience substantially exceeded that of the capuchins, even of those in the experience condition. Therefore, it is perhaps reasonable to consider that the capuchins' extra 15 trials on the task no more than partly compensate for this, suggesting that the underlying tool-using abilities of capuchins closely resembles that of chimpanzees.

Visalberghi and colleagues have argued that a "persistence of errors across blocks of trials suggests that the subjects did not achieve a full comprehension of the requirements of the task" (Visalberghi et al., 1995, p.58). They have also argued that a decrease in errors across blocks of trials suggests that the subjects "can acquire more readily those associations relevant to solution of the task" or, as they claimed equally plausible, "acquire a fuller comprehension of the task" than do subjects who persist in error performance (Visalberghi et al., 1995, p.58). These arguments were used to support the claim that apes had a fuller comprehension of the task than did the capuchins tested in their study. Remember, though, that their capuchin subjects had not had experience with the objects used in the task, nor had they been exposed to the same human-like cultural environment as had the apes. Additionally, they had only been given ten trials on the task. It is interesting then, that the capuchins in the current study not only improved their performance across all 25 trials, but they did so significantly across their first ten trials as well. This improvement in the capuchins' performance was evidenced by a decrease in their frequency of errors, an improvement which had not been achieved by the chimpanzees, although they started out with a relatively low frequency of errors, thus explaining the insignificant decrease. The capuchins' improvement was further evidenced by a decrease in trial completion times, as had been achieved by the chimpanzees, although the difference was not statistically significant. Applied to the capuchins in the current study, Visalberghi et al.'s (1995) arguments suggest that capuchins with object experience have as full a comprehension of the requirements of the task as do chimpanzees because they make as few errors as do the chimpanzees after experience with the objects.

Further, Visalberghi et al. (1995) argued that persistence in inserting unmodified tools into the tube "revealed a lack of comprehension of the important properties of the stick for its function as a tool" (p.53). Therefore, because the experienced capuchins in this experiment decreased their attempts to insert unmodified pipes to the point where they modified them before attempting to use them on almost every trial (see Chapter 4), it can be argued that they learned the important properties of the pipes which allowed them to function as tools during the task. This is consistent with the results from Experiments 5 and 6 in which the capuchins exhibited an appreciation for the relevant properties of the objects (see Chapter 6).

However, despite the evidence for capuchins' ability to learn the relevant properties of objects, and perhaps even some of the requirements of the tool-modification task, their unsuccessful performance on the trap-tube task (see Experiment 4, Chapter 5) failed to provide evidence for their ability to understand the cause-effect relations involved in tool-using tasks. In comparison, Limongelli et al. (1995) found that two of the five chimpanzees tested on the trap-tube task reached successful levels of performance after they had completed 70 trials on the task. Further, they both dislodged rewards significantly more often with single insertions than with multiple insertions of the tool into the tube. Limongelli et al. suggested that these results indicated "that the success of [the two chimpanzees] may have been based on a causal understanding of the relation between action and outcome, because their performance took into account the position of the trap, which is a crucial feature of the trap-tube task" (p.25). The success of these two chimpanzees, as compared to the lack of success for both the experienced and non-experienced capuchins, could suggest a possible species difference in capacity for causal understanding. Alternatively, this understanding may have been facilitated by the cultural influences present in the chimpanzees' environment. As has been suggested by Tomasello and Call (1997), the treatment of the chimpanzees as intentional individuals may have led to their deeper understanding of intentions, or the means-ends structure of behavior, for inanimate, as well as animate, events.

The fact that it took the chimpanzee subjects 70 trials before they supposedly acquired this causal understanding of the task suggests, however, that associative learning may have had a greater influence on their success than had been claimed. It is certainly plausible that these chimpanzees learned to associate the position of the reward in the tube, with respect to the trap, with inserting the stick into a certain end of the tube. The one capuchin subject found to be successful on the trap-tube task in Visalberghi and Limongelli's (1994) study was claimed to have achieved success through the use of a distance-based rule, in which the reward's distance from the end of the tube became associated with insertion of the stick into a certain end of the tube. The chimpanzees could have learned a similar rule which involved judging the reward's distance by looking through the transparent tube, as opposed to in the ends of the tube, or judging the side of the trap to which the reward was placed. In fact, when Limongelli et al. (1995) presented the two chimpanzees with another condition of the trap-tube task in which the trap was placed off-center, thus reversing the distance-based rule, if they had been using one, only one subject continued to dislodge the rewards with single insertions whereas the other achieved success through multiple insertions on at least half of the trials. Therefore, only one chimpanzee continued to use what appears to be a representational strategy based on a causal understanding of the task. The other chimpanzee used an anticipatory strategy, just as the capuchin had in the original trap-tube task; thus it is possible that this strategy also involved the use of a rule similar to the capuchin's distance-based rule to solve the task. It should be noted, however, that when the capuchin was tested with the shifted-trap tube, her performance on the task was below chance. Furthermore, the fact that the other three chimpanzees did not achieve successful performance on the trap-tube task, and in fact did not differ in performance from the capuchins (see Limongelli et al., 1995; Experiment 4, Chapter 5), supports the idea that perhaps the underlying tool-using abilities of these two species are quite similar.

In sum, comparison of *Cebus* and *Pan* tool-using ability has shown that whereas capuchins with object experience may be capable of acquiring as full an understanding as chimpanzees of the requirements of the task involving modification of the tool object, therefore, of showing an appreciation for the characteristics which allow the object to function as a tool, they have yet to exhibit a capacity for understanding the causal relations involved in these tasks. The capuchins' similarity of performance with respect to the chimpanzees contradicts previous research which had found that capuchins did not improve their performance across ten trials, and persisted in making more errors than had chimpanzees (Visalberghi et al., 1995; see also, Visalberghi & Trinca, 1989). This discrepancy in capuchin performance between the studies suggests that experiential history is an important factor in tool-using performance. Whereas the capuchins in the previous studies had not had the opportunity to manipulate the task materials before testing, the experienced capuchins in the current study did have that opportunity, and thus were more experienced at the start of testing, as were the chimpanzees. Consistent with previous research with nonhuman primates (Birch, 1945; Call and Tomasello, 1996; Jackson, 1942; Schiller, 1957), this comparison supports the claim that interaction with objects enhances the ability to use those objects as tools. Therefore, it is perhaps fair to say that Visalberghi and colleagues (Visalberghi et al., 1995; Visalberghi & Trinca, 1989) were premature in their assessment of capuchin and ape differences in tool-using ability. Although chimpanzees with extensive language and object experience seem to understand the requirements of a tool modification task after only a few trials, capuchins seem able to appreciate the task requirements as readily as do the chimpanzees once they have also been exposed to the task objects and have had a chance to explore them.

The performance of the capuchins on the trap-tube task concurs with previous research which has claimed that capuchins are not capable of understanding causal relations (Limongelli et al., 1995; Visalberghi & Limongelli, 1994). However, the similar performance of the chimpanzees to that of the capuchins, including the two "successful" chimpanzees' first 70 trials, suggests that chimpanzees may not really be fully capable of understanding the causal relations involved in the trap-tube task either. It is possible that this task represents a cognitive limitation for these animals because it requires the capacity for understanding the complex, cause-effect relations between the tool's movement through the tube and the resulting displacement of the reward either into the trap or out of the tube. The other tube tasks presented required a less cognitively-complex understanding of the features that make an object function as a tool. Other experiments have shown that capuchins are capable of this level of understanding (Anderson & Henneman, 1994; Westergaard & Fragaszy, 1987; Westergaard et al., 1998; see also, Experiments 5 and 6, Chapter 6), but it has yet to be shown that capuchins have an understanding of the cause-effect relations involved in problems like the trap-tube task. However, without examining the ability of capuchins raised in the same human-like cultural environment as that of the apes in these studies, and without testing them on at least as many trials as had been given to the apes, it would be premature to conclude that capuchins *cannot* understand such relations.

Chapter 8

Conclusions

To conclude, the aims of this thesis were: (1) to shed further light on the effects of object manipulation experience on tool-using ability, (2) to clarify the extent of capuchin tool-using ability, and (3) to assess whether the enculturation of apes may have confounded previous comparisons of cognitive processes underlying capuchin and ape tool-using behavior. Addressing the first aim, Experiments 1 and 3 demonstrated the beneficial effects of experience on capuchins' performance on two variations of a tool-using task, suggesting that experience either reduced curiosity towards novel objects or increased knowledge about the objects' affordances in relation to the task. A third explanation was also suggested: that group differences were the result of social learning influences. As discussed in Chapter 6, the data from Experiments 1 and 3 supported the interpretation that experience provided the capuchins with an opportunity to explore the affordances of the objects in relation to the task, thus increasing the efficiency with which they used those objects as tools to solve the task. Social learning was rejected as an explanation of the group differences because the data contradicted the results expected by such influences. Therefore, concurrent with previous research with nonhuman primates (Birch, 1945; Jackson, 1942; Schiller, 1957), object experience did have a beneficial effect on tool-using behavior by allowing the monkeys to explore the functions of the objects in a non-goal-directed manner before having to use them to obtain the reward.

Addressing the second aim, Experiment 4 suggested a limit to the capuchins' tool-using ability, as it failed to provide evidence that they understood the causal relations involved in the trap-tube task. Only one capuchin has ever achieved consistent success on that task, after 80 trials (Visalberghi & Limongelli, 1994), however she did so using an anticipatory strategy, and thus did not display an understanding of the cause-effect relations involved. Therefore, at this time, there is no evidence that capuchins are capable of understanding these complex relations. However, the possibility cannot be ruled out without further research. In the future, this could be examined by testing capuchins raised in a human-like cultural environment similar to that of the apes, or by providing a form of experience which would enhance their knowledge about the function of traps. Similarly, unenculturated, mother-reared chimpanzees should also be tested on these tasks since evidence for causal understanding comes from two chimpanzees raised in an enculturated environment and their performance may have been facilitated by those cultural influences.

Although understanding causal relations may be outside the limitations of capuchins' ability, distinguishing between the functional characteristics of objects was demonstrated to be within their ability. In Experiments 1 and 3, the capuchins nearly always used potential tool objects for solving the task (as opposed to 'T' caps or other non-tool objects in the cage) and proved capable of modifying initially unsuitable objects to create suitable tools. Further, the experienced capuchins decreased their repertoire of ineffective behaviors for solving the task, thus reducing their performance of errors. This suggests that they may have some understanding of the type of tool necessary for solving a task. Experiments 5 and 6 provided additional evidence for the capuchins' appreciation of functional differences between objects in their use as tools; the experienced capuchins chose an unfamiliar object with the correct properties to be effective as a tool when a familiar but ineffective object was also provided, and one subject consistently connected short pipes together correctly. Therefore, these findings were consistent with Anderson and Henneman (1994), Westergaard and Fragaszy (1987b), and Westergaard et al.'s (1998) suggestions that capuchins could appreciate such differences, however they contradict Visalberghi and Trinca's (1989) claims that capuchins are unable to appreciate the differences between objects which make them appropriate for use as tools. It is possible that only after having had the chance to explore the objects, as had the experienced capuchins in the current experiments, that capuchins can appreciate these differences. However, future research is necessary to elaborate on the nature of capuchins' understanding of these differences, perhaps through an experiment similar to Hauser's (1997) investigation with tamarins, in which they are required to choose between objects with varied functional (shape and size) and non-functional (color and texture) characteristics for use as tools.

Evidence supporting the beneficial effects of object experience on tool use, as well as that suggesting capuchins *can* distinguish between the functional properties of objects in their use as tools, addresses the third aim, suggesting that a human cultural influence in the rearing of one group of subjects can confound any comparisons of tool-using ability with subjects lacking the same influence. Thus, it is probable that the chimpanzees in Visalberghi et al. (1995) and Limongelli et al.'s (1995) studies had an advantage over the capuchins on the tool-using tasks because of their extensive experience with objects. Further, Chapter 7's comparison of capuchin and chimpanzee performance on the tool modification condition of the tube task displayed the similarity of performance between the capuchins with manipulative and task experience and the enculturated chimpanzees. Therefore, the gulf between capuchins' and chimpanzees' abilities may not be as great as claimed considering that experience with objects, or human enculturation, had enhanced the abilities of the chimpanzees used for comparison. Future research is necessary to clarify more specifically what these species differences are, and should do so by comparing species with exactly the same rearing histories, cultural influences, and experiential backgrounds.

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