PROBLEM SOLVING THROUGH TOOL USE IN ASIAN ELEPHANTS

by

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A dissertation submitted to the Graduate Faculty in Psychology in partial fulfillment of the
requirements for the degree of Doctor of Philosophy
The City University of New York

2012

The manuscript has been read and accepted for the
Graduate Faculty in Psychology in satisfaction of the
Dissertation requirements for the degree of Doctor of Philosophy

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Abstract

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Spontaneous problem solving without evident trial and error behavior has been referred to as insight. Surprisingly, elephants, thought to be highly intelligent, have failed to exhibit insightful problem solving in previous cognitive studies. I conducted ten experiments investigating problem solving through tool use on three Asian elephants. Experiment 1 was designed to test means-end recognition. Trays with food placed on one end were positioned outside the bars of the elephants' stalls. Each of the elephants pulled the tray, showing understanding of the means-end relationship. In Experiments 2 and 3, I tested if elephants would use sticks as tools to reach food trays placed just beyond their trunk reach or use sticks to knock out-of-reach fruit from an artificial tree. None of the elephants employed sticks to accomplish either task. A chain pulling problem to attain food through a multi-step solution was presented in Experiment 4. All elephants solved the problem and one completed the task immediately, suggesting insightful problem solving. In Experiment 5, I investigated if elephants, when presented with different types of potential tools, a movable platform and sticks, would show tool use to reach food suspended overhead, out-of-reach. Without prior trial and error behavior, a 7-year-old male showed spontaneous problem solving by moving a large plastic cube, on which he stood, to acquire the food. In Experiments 6-8, I tested if the elephant would generalize this ability to other positions and objects, which he demonstrated. In Experiment 9, I examined if tool use with sticks differed in relation to suspended food or an object. No difference was found. Social learning was tested in Experiment 10 by having one elephant demonstrate the solution to a tool

use problem while a second elephant observed. No social learning was exhibited. The elephant's behavior in experiments 5-8 was consistent with the definition of insightful problem solving. Previous failures to demonstrate this ability in elephants may have resulted not from a lack of cognitive ability but from the presentation of tasks requiring trunk-held sticks as potential tools, thereby interfering with the trunk's use as a sensory organ to locate the targeted food.

ACKNOWLEDGEMENTS

I would like to thank my dissertation advisor Dr. Diana Reiss for her tireless support, advice, and encouragement to go ever deeper into my research; Dr. Sheila Chase, without whom I might never have entered the Ph.D. program and has been a source of wisdom and encouragement throughout my graduate school career; Dr. Martin Chodorow for his help and advice, statistical and otherwise, since my M.A. studies; Dr. Donald E. Moore III for providing an easy path for the research at the Smithsonian National Zoological Park and encouragement to go on when I most needed it; and Dr. Patricia Cole for her advice, caring and availability to listen to my problems through the stressful times.

I would like to thank Marie Galloway who was always willing to do whatever it took to make this research possible and went out of her way even when I was willing to take a break; Tony Barthel, for his help and elephant consultations; and Debbie Flinkman, Sean Royals, Brad Hange, and the rest of the elephant keeping staff. All of these people know more about the behavior of these animals than I ever will. I would also like to thank the elephant house volunteers who were always willing to help.

I could not have done this research without the invaluable help my student volunteer research assistants both at the zoo and in the lab: Abby Knop, Alison Rush, Jessica Alva, Jean Berger, Sherri Loveless, Kristi Collom, and Maggie Zambrano. I would like to thank Dr. Sonia Ragir for her help with Subtrak and in general.

I need to thank my lab mates and comrades-in-arms, Dr. Maria Maust-Mohl, Daisy Kaplan, Rachel Morrison, Heather Spence, for their advice, support, and shoulders to lean on.

I thank the current head of our program in Biopsychology and Behavioral Neuroscience, Dr. Mark Hauber for his animal behavior knowledge and for always being willing to lend an ear and give his advice. I am also grateful to our department’s Program Administrative Assistant, Ellen Breheny, without whom our program would cease to function.

My first mentor in the program was Dr. Jim Gordon, for whom I was a teaching assistant and lab member for my first semester. His guidance in teaching and research has shaped who I became as a teacher and scientist.

I would like to thank all the people who either arranged for a place for me to stay or put me up in their spare rooms and on their sofas during my frequent trips to Washington, DC: Lynnie Raybuck, Brian Vastag, Rob Frederick, Donna Scheidt, Margaret Cassilly.

I thank the Graduate Center of the City University of New York for two Doctoral Student Research Grants that helped in the completion of the research and its dissemination at conferences.

I could not have gotten through this without the love and support of my wife and in-house copy editor, Dr. Sarah Webb. I love you.

And, of course, thank you to John Boos & Co. for generously providing the butcher block cutting boards.

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Chapter 1: General Introduction

The lives of elephants and human beings have been entwined throughout history. Our ancestors may have been responsible for their extinction in the Americas during the Pleistocene era. For more than 4,000 years, humans have trained elephants to serve as war and work animals. Today, our appropriation of their natural territories may once again lead to their extinction (Sukumar, 2003). Through all our close contact with elephants, we have come to consider them as an intelligent species with advanced cognitive abilities. Although many anecdotal accounts note the cognitive abilities of elephants remarkably few scientific investigations have actually been conducted (Bates & Byrne, 2007). A 2009 review of elephant cognition research (Byrne, Bates, & Moss) revealed only 21 papers published in peer-reviewed journals.

My research investigates problem solving through tool use in Asian elephants through a series of ten experiments. In particular, the elephants' behavior was examined to determine if they showed insightful problem solving. While elephants have shown many abilities including a facility with tools (Irie & Hasegawa, 2009), previous research has shown that they perform poorly in insightful problem solving tasks (Hart, Hart, & Pinter-Wollman, 2008; Nissani, 2004). To further investigate this apparent lack of ability in this particular cognitive realm, I ran a series of experiments testing the ability of Asian elephants to use tools to solve problems across a variety of situations.

Species Background

The actual number of species and subspecies of elephants has long been debated. Asian elephants (*Elephas maximus*) are considered a separate species from African elephants (*Loxodonta africana*). The Asian elephants were thought to have three distinct subspecies: Mainland (*E. m. indicus*) Sri Lankan (*E. m. maximus*) and Sumatran (*E. m. sumatranus*). More recent DNA studies indicate little differentiation between the mainland and Sri Lankan elephant, although there is support for a Sumatran subspecies (Sukumar, 2003).

Early twentieth century estimates of African elephants listed as many as eighteen subspecies. This estimate was later reduced to two subspecies forest elephants (*L. a. cyclotis*) and savanna elephants (*L. a. africana*) though there was great debate over whether these were, in fact, separate species of elephant (Sukumar, 2003). Recent genetic analysis (Rohland et al., 2010) comparing both species with mammoth and mastodon mitochondrial and nuclear DNA has determined that the African forest and savanna elephants are two distinct species.

African elephants range from southern Africa through central eastern and western Africa although the populations in places are extremely isolated. Asian elephants range from India through southeast Asia to Indonesia (Sukumar, 1991). The population estimates for both species of African elephants range from 470,000 - 690,000 individuals (WWF, 2012) and 41,410–52,345 for Asian elephants (Choudhury et al., 2008).

Physical characteristics. Asian and African elephants have many physical differences. In size, Asian elephants are smaller than African elephants, a maximum of 5000 kg and 3.5 m at the shoulder as opposed to 7000 kg and 4 m. Asian elephants have a convex back, smaller ears and a double domed head. African elephants have a concave back, much larger ears, and a flattened head. In Asian elephants only the males have tusks while both sexes of African elephants sport tusks: the males' tusks are larger. The Asian elephant's trunk is more rigid and ends in a single trunk "finger" at the end while the African elephant is less rigid and ends in two "fingers" (Shoshani, 1991).

The elephant's trunk is such a distinct and unique feature of its anatomy that when Carl Illiger named the order for elephants in 1911, he referred to them as Proboscidea for proboscis or nose. There are currently 164 species of proboscideans including the three extant species in the family Elephantidae (Shoshani, 1998). The earliest proboscidean known from the fossil record is the moeritherium, an animal resembling the tapir. Theorized to be aquatic or semi-aquatic, this animal's amphibious lifestyle has been corroborated by dental isotope analysis (Liu, Seiffert, & Simons, 2008). The aquatic nature of the elephant's antecedents is important for understanding its current appearance. Like modern marine mammals, the male elephant has intraabdominal testes. The trunk may have evolved initially as a snorkel, a use seen in modern elephant when submerged in water. The closest relatives to the elephants in the superorder Afrotheria are the aquatic Sirenians, manatees and dugongs (Gaeth, Short, & Renfree, 1999).

Sensory characteristics. Elephants have dichromatic vision similar to human deuteranopes (red-green colorblind), which is thought to be better in dim than bright light (Yokoyama, Takenaka, Agnew, & Shoshani, 2005). The monocular field for each eye is 190° with an overlap of 67° in the front for binocular vision. There is a 47° blindspot behind the head as well as one directly in front of the head between the eyes (Suedemeyer, 2006). While vision is not their primary sense, it is assumed to be good enough to see the many postural gestures of elephant communication (R. W. Byrne, et al., 2009). In a more recent study of the retinal ganglion density of the African elephant, Pettigrew et al. (2010), estimate that the elephant's vision is better than previously supposed. They estimate the maximum visual acuity to be 13.16–14.37 cycles/degree. This would make the elephant's visual acuity 4.5 times less than a human but greater than that of a domestic cat. They also found that the elephant eye has two fovea: one focused outwards and a second focused on the area of the trunk. Using both eyes the elephant can obtain visual information about the trunk in three dimensions. Some testing has shown that

Asian elephants may have higher visual acuity than African elephants (Shyan-Norwalt, Peterson, Milankow King, Staggs, & Dale, 2010).

Far more acute is the elephant's hearing. Although elephants cannot hear above 10 kHz as compared to 19 kHz in humans, they can hear infrasonic sounds down to 17 Hz (and perhaps lower) compared to 29 Hz in humans. (Heffner & Heffner, 1980; Suedemeyer, 2006). Elephants are the first terrestrial mammals found to communicate infrasonically (Payne, 1998) and are capable of sensing seismic communications through the ground. Inside the ear, the massive ossicles may allow them to hear sound through bone conduction through their feet (O'Connell-Rodwell, 2007; Reuter, Nummela, & Hemila, 1998).

Along with hearing, another essential sense for the elephant is olfaction. The Asian elephant has seven turbinals, the chemosensory lined bony plates in the skull. Comparatively, dogs have five turbinals and humans have three (Shoshani, 1997). The sensory sensitivity of the elephant olfactory system has been described as "awesome" (Rasmussen, 2006). Elephants can use olfaction to distinguish relationships with other elephants (Bates, Sayialel, et al., 2008). They can also discriminate the smell of human tribes with a previous history of elephant hunting from those who do not hunt.. (Bates et al., 2007). The elephant's vomeronasal (VNO) system enables the animal to discriminate individuals, relationships, sexual states, and group status (Rasmussen, 2006). The trunk tip plays a vital role in their ability to distinguish pheromones. The flemen response consists of the elephant dipping the tip of the trunk into a pheromone laden substance, such as urine, and touching it to the VNO organ at the roof of the mouth. The mucous in the trunk tip contains odorant binding proteins which release the pheromones for perception (Lazar, Greenwood, Rasmussen, & Prestwich, 2002). In the brain, the elephant has a large olfactory bulb and higher olfactory processing area. However, elephants have no accessory olfactory bulb, the structure usually involved in pheromone processing. It is assumed that the main olfactory bulb has taken over that function (Ngwenya, Patzke, Ihunwo, & Manger, 2011).

The elephant's trunk is a unique appendage. As a nose, the length of it warms inhaled air with volatile odorants to 37°C increasing their perceptibility. Besides the trunk's olfactory use, it is a highly manipulable appendage. Comprising the conjoined upper lip and nose, the trunk is made up of about 150,000 muscle fascicles (subunits). Elephants can lift up to 300 kg with their trunks and hold up to 10.22 liters of water (Shoshani, 1997). Moss (2000) tells of elephants killing cattle merely by striking them with their trunks. The African elephant trunk may be more elastic while the Asian elephant's trunk is more dexterous. Trunks are used for manipulating, lifting, eating, breathing, vocalizing, and social disciplining. Elephants use their trunks to determine scent direction, using the uplifted trunk as a periscope (Rasmussen, 2006; Shoshani, 1997).

The tip of the elephant's trunk is extremely tactile. Its sensory innervation has been compared to that of rodent mystacial skin or the lip skin of monkeys. The tip has a high density of free nerve endings, small, multibranched corpuscles, and many small Pacinian corpuscles. There are two types of vibrissae innervated by hundreds of axons. Surrounding the tip are regular vibrissae, and within the skin, but not protruding, are short vellus vibrissae. This dense sensory innervation may enable the trunk finger to grasp small objects (Rasmussen, 2006; Rasmussen & Munger, 1996). The tip is sensitive enough to pick up a single straw the width of a needle (Shoshani, 1997). Rasmussen (2006) describes the trunk tip as a "refined eating tool."

Social structure. Elephants have a complex social system. Until recently our knowledge of elephant social structure was based on extensive studies of African savanna elephants. African savanna elephants have a hierarchical structure within the elephant social system. The smallest group comprises a family unit of between 8 and 20 related female members and sub-adult males. The bond group consists of closely associated family groups. The clan includes bond groups that tend to share the same territories and are acquainted with each other, but not as closely tied as the bond group. The sub-population are bond groups that merely share territory, and the population are elephants in sub-populations within a study area (Moss, 2000). Family groups are led by the eldest female, the matriarch. There are clear hierarchies within and between groups, as well as in all-male bachelor groups (O'Connell, 2007; Sukumar, 2003). The society depends on a high degree of sociality, including allomothering, social helping, and cooperation (Bruce, 2000). Elephants also exhibit fission-fusion sociality on both short and long term scales; the groups divide and reform over the course of the day, as well as over the course of a generation (Moss & Lee, 2011). Compared to the savannah elephant, the African forest elephant (*Loxodonta cyclotis*) lives in small family groups that do not seem as bonded to other groups (Sukumar, 2003).

Although it had been thought that Asian elephant social structure had similarities to African elephants, a recent study (de Silva & Wittemyer, 2012) has revealed differences in their social organization. As compared to the African elephants, Asian elephants have smaller, less coherent groups and are less socially connected at the population level. They do not maintain the large family groups seen in African elephants and do not show the hierarchical organization seen in African elephants. In spite of these differences, Asian elephants show a connected, social network, maintaining consistent relationships with other elephants in the short and long term.

Communication

Elephants communicate through multiple sensory channels. They utilize visual, tactile, chemical and acoustic signals (Sukumar, 2003). Visual and tactile gestures can be used for aggression, social integration, and mother-offspring bonding (Poole & Granli, 2011). The elephant’s eyesight has evolved to take advantage of large signals at a distance and smaller signals and identity markings at close range (Pettigrew, et al., 2010).

Chemical signals are conducted primarily through pheromones. These signals can communicate identity, diet, or fertility state. Males in musth, the breeding period typified by extremely high testosterone levels, give off vast amount of pheromones from their temporal glands and urine to advertise their breeding state (Rasmussen, 2006). Bates, et al. (2008) have shown that elephants can recognize up to thirty family members based on scent cues in their urine.

Elephants communicate acoustically with other elephants both within and out of visual range. Acoustic signals range from 5 Hz to 10kHz (Sukumar, 2003). Female calls are used primarily for social cohesion and group coordination. Male calls appear to have a wider range of uses including aggression. Elephant calls range from chirps and squeaks to trumpets, rumbles, and roars (Langbauer, 2000). Infrasonic calls may travel long distances and be heard seismically through bone conduction via acoustic fat in the feet to the ear or through somatosensory receptors in the feet (O'Connell-Rodwell, 2007).

Elephants are one of the few mammalian species that have been shown to be capable of vocal learning (Poole, Tyack, Stoeger-Horwath, & Watwood, 2005). An African elephant mimicked the sounds of passing trucks, and another African elephant kept in a zoo with Asian elephants produced a species-specific vocalization, a chirp, only made by Asian elephants.

Elephant Cognition

Elephant intelligence may have evolved in response to a need to determine the complex hierarchies of their social structure. Byrne and Whiten (1997) have deemed this “Machiavellian intelligence,” the theory that intelligence is “linked with social living and the problems of complexity it can pose” (p. 1). Bates, et al. (2008) have shown that African elephants can recognize and keep track of the locations of up to 30 family members. This capacity shows both memory and the ability to categorize. The elephant society‘s fission-fusion organization requires the animals to constantly reorganize and remember these relationships. Poole and Moss (2008a) see signs of elephant Machiavellian intelligence in greeting displays, third party reconciliation of disputes, and tactical deception.

Cooperation is facilitated by the capacity for empathy (Preston & de Waal, 2002). In a 35-year study of the behavior of African elephants, Bates, et al. (2008), reported hundreds of examples of behavior that they considered indicative of empathy and cooperation. These included creating coalitions, babysitting and retrieving errant calves, and assisting other elephants that had mobility problems. Most famously elephants display apparent empathetic behavior in their reactions to dead conspecifics. Douglas-Hamilton, et al. (2006) tracked reactions of other African elephants to the death of a matriarch. They documented other elephants trying to help the matriarch to stand as she was dying. After she died, a companion stayed with the body, guarding it, and numerous other elephants investigated the carcass, going out of their way to approach it. Research also shows that elephants will show much greater interest in elephant skulls and ivory than in skulls of other animals or other natural objects (McComb, Baker, & Moss, 2006). Plotnik et al. (2011) have shown that elephants have an understanding of cooperation. When presented with a tray pulling task to obtain food in which it was necessary for both elephants to pull ropes to move the tray, one elephant would wait for a second delayed elephant before pulling on its rope.

A correlation between the ontological and ontogenetic emergence of empathy, theory of mind and mirror self-recognition has been postulated (Gallup, 1970; Preston & de Waal, 2002).

As MSR was initially found in chimpanzees but not monkeys, it was theorized that this ability marked an evolutionary difference between great apes (including humans) and other animals (Gallup, 1970). However, MSR has been shown not only in humans (Amsterdam, 1972) and great apes (Gallup, 1970), but also in dolphins (Reiss & Marino, 2001) and in magpies (Prior, Schwarz, & Güntürkün, 2008). Although some researchers have reported negative results for MSR in elephants (Nissani & Hoefler-Nissani, 2007; Povinelli, 1989), methodological problems may have hampered the elephants showing the ability. In one case (Nissani & Hoefler-Nissani, 2007) the elephants were marked by taping a feather to their heads instead of the standard mark test. In the other case (Povinelli, 1989), a relatively small mirror was placed at an angle outside the bars of the elephants' enclosure. The distance, position and size of the mirror prohibited the elephant from seeing her whole body or approaching and touching the mirror (Plotnik, de Waal, & Reiss, 2006). In a more thorough examination, Plotnik, de Waal, & Reiss (2006) tested three Asian elephants at the Bronx Zoo and reported that all three showed self-directed behavior in the mirror and one passed the mark test, providing evidence for MSR in this species.

Rensch (1956) postulated that larger brains implied greater learning abilities in animals. This theory led him to investigate the terrestrial animal with the largest brain – the elephant. To test this theory he conducted a series of experiments on a 5-year-old Asian elephant at the Münster Zoo (Rensch, 1957). Impressed by the number of verbal commands that trained Thai elephants could differentiate, Rensch tested to see how many pairs of visual symbols the elephant could discriminate for reinforcement. The elephant was presented with two symbols, a circle and a cross, only one of which (the cross) resulted in food reinforcement when lifted. The elephant learned the discrimination of the first pair, after 330 trials. After this initial discrimination, the animal learned succeeding pairs much more quickly, eventually recognizing the difference between 20 different pairs of symbols. The elephant was able to retain this ability to discriminate the symbols when tested a year later. In a further study, the elephant was tested on its ability to discriminate between different frequencies of sounds and different orders of notes. She was shown able to make this discrimination as well. Nearly twenty years passed before the next published research showing that elephants remembered a similar visual discrimination task after eight years (Markowitz, 1975). Asian elephants have been shown capable of olfactory discrimination learning in a similar testing procedure (Arvidsson, Amundin, & Laska, 2012). There also may be an age effect in discrimination learning in elephants – older elephants (over 20) showing less ability to learn the task (Nissani, Hoefler-Nissani, Lay, & Htun, 2005).

Recently, cognitive research on elephants has advanced more rapidly, and elephants have been shown capable of many advanced cognitive abilities. Irie-Sugimoto, et al. (2008) established that Asian elephants are capable of means-end recognition by showing that the animals understand that pulling on one end of a tray will bring food supported on the opposite end closer, a task human infants do not understand until they are approximately eleven months old. In a further experiment (Irie-Sugimoto, Kobayashi, Sato, & Hasegawa, 2009) , the researchers found elephants capable of relative quantity judgment. The elephants could detect a bucket with a greater amount of food both by sight and by seeing items of food dropped individually in the buckets and chose the bucket with the greater amount in both cases. In audio playback experiments, McComb, et al. (2011) have shown that families wild African savanna elephants are capable of discriminating between the sounds of a single lion roaring and three lions roaring and that the sensitivity to this discrimination increases with the age of the matriarch. Bates, et al. (2008) have shown that African savanna elephants can keep track of up to thirty family members and their locations based on the odors of samples of urine left on the ground. African elephants have also been shown to discriminate predatory tribes of humans from non-predatory based on olfactory cues and clothing color (Bates, et al., 2007).

Tool Use

Tool use has often been used as an indicator of intelligence, but that requires a precise definition of what a tool is. Van Lawick-Goodall (1970, p. 195) defined a tool 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.”

However, this definition does not take into account the difference, for example, between hitting a piece of fruit with a stick or hitting it against a tree to open it (Benjamin B. Beck, 1980). Later, Alcock (1972) refined the definition to “the manipulation of an inanimate object, not internally manufactured, with the effect of improving the animal’s efficiency in altering the form or position of some separate object.” (p. 464) This definition did not take into account a monkey throwing feces (internally manufactured).

Beck (1980) expanded the definition to what has become the standard for describing a tool:

> 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).

In order to include items of measurement and other forms of tools that convey information, as well as describe tools that remain attached to something else, for example by a rope or branch, St Amant and Horton (2008) recently revised the definition once again.

> Tool use is the exertion of control over a freely manipulable external object (the tool) with the goal of (1) altering the physical properties of another object, substance, surface or medium (the target, which may be the tool user or another organism) via a dynamic

> mechanical interaction, or (2) mediating the flow of information between the tool user and the environment or other organisms in the environment (p. 1203).

Finally in a recently revised and updated version of Beck's *Animal Tool Behavior* (Shumaker, Walkup, & Beck, 2011), the authors have amended Beck's original definition to take into account the previous modifications.

> The external employment of an unattached or manipulable attached environmental object to alter more efficiently the form, position, or condition of another object, another organism, or the user itself, when the user holds and directly manipulates the tool during or prior to use and is responsible for the proper and effective orientation of the tool (p. 5).

The basic qualities of a tool drawn from these different definitions seem to be that it be moved by the organism to affect something else. Some researchers argue that construction of structures such as dams and nests be included in tool use in that they are not biologically distinct from the act of using a tool (Hansell & Ruxton, 2008). For the purposes of this study, I will use Beck's updated definition which excludes structures as they are not held or carried.

Does this extensive tool use indicate intelligence? Not necessarily. Beck (1980) in his exhaustive study of tool use notes this ability not only among primates and elephants, but also rodents, birds, fish, crustaceans, mollusks, and insects. Archer fish (*Toxotes jaculatrix*) squirt water to knock insects into the water to eat. Wasps of the *Sphex* genus deposit their larvae in burrows, provision them with food, and recover the burrows by pounding the dirt in with sticks, pebbles or other objects. The antlion, the larvae of flies of the genus *Myrmeleon*, dig small pits, wait at the bottom and when prey falls into the pit, they throw sand at the prey to knock it within reach. Tool use behavior arises in certain species when raised in isolation. Tebbich, Taborsky, Fessl, and Blomqvist (2001) showed that naïve woodpecker finches developed stick foraging behavior even when they had never been exposed to the behavior. Examples such as these imply an innate aspect to the ability to use tools rather than intelligence.

Tool use has been conflated with intelligence since anthropologists defined man as the tool user. When Jane Goodall first discovered that chimpanzees fished for termites using sticks as tools in 1960 (van Lawick-Goodall, 1970), she received a letter from Louis Leakey stating “Now we must redefine 'man,' redefine 'tool' or accept chimpanzees as humans.” ("Jane Goodall Institute," 2009). While some tool use may be intelligent, not all tool use is. The definitions of tool use exclude intelligence; so it may be necessary to focus on whether the particular instance of tool use exhibits intelligence or not (Shumaker, et al., 2011). Intelligence may be revealed through tool use if the tool is used to solve a problem.

Elephants have shown the greatest frequency and diversity of tool use of any non-primate mammal (Beck, 1980b). In a review of elephant tool use in both captive and wild elephants, Chevalier-Skolnikoff and Liska (1993) found 21 types of tool use in captive elephants and 9 types in wild elephants. More than 80% of their examples of tool use, for both captive and wild elephants, were for body care, including fly swatting, scratching with objects, and throwing water or dirt on the body. Besides body care, tool use by captive elephants included aggressive and ambiguous usage. Wild elephants also showed aggressive tool use, and ambiguous use towards a dead conspecific (throwing dirt on the body). Douglas-Hamilton (1975), has seen wild African elephants rub their cuts with clumps of grass. Both he and Poole (1996) have seen elephants throw logs in aggressive displays. Elephants wad up vegetation to block and hide wells that they have dug (Gordon, 1966) and disable electric fences by dropping logs on their wires (J. Poole & Moss, 2008b). Hart et al. (2001) have documented the use of branches as tools to swat flies and tool manufacture. Elephants pull down branches and alter them to the appropriate size and shape for use as a fly switch. The elephant’s capability with tools is facilitated by an amazingly deft and manipulable appendage that other animals lack, its trunk.

Insightful Problem Solving

From the beginnings of experimental psychology, researchers have used problem solving to investigate intelligence. Thorndike (1898) placed cats in puzzle boxes, forcing the animals to solve the problem of how to escape and obtain food reinforcement. From this research Thorndike derived his law of effect: an outcome that produces satisfaction will increase the frequency of the behavior that it follows, and an outcome that produces discomfort will decrease the frequency of the behavior that it follows. This law became the basis of behaviorism. Thorndike's conclusion, surprisingly for a work entitled "Animal Intelligence," was that no intelligence was involved; instead it was purely association by chance. Thorndike's description of a "problem" is still definitive:

> A problem exists when the goal that is sought is not directly attainable by the performance of a simple act available in the animal's repertory; the solution calls for either a novel action or a new integration of available actions (Scheerer, 1963, p. 27).

Wolfgang Köhler (1925) differed with Thorndike about animal problem solving. As one of the founders of Gestalt psychology, Köhler thought that there was more to problem solving than stimulus and response (Scheerer, 1963). He asserted that Thorndike's cats could not exhibit intelligent behavior because the situation prohibited them. The cats were incapable of seeing the hidden mechanism of opening the puzzle box. Köhler maintained that it was necessary for an animal to be able to take in all of the aspects of the problem at once (Köhler, 1925). From 1913-1917, Köhler conducted a classic series of experiments with chimpanzees on Tenerife in the Canary Islands, putting them in situations in which they could see a food item that they could not reach. In the majority of the experiments, the chimps were provided with a number of objects which they could use to obtain the food: sticks, long boards, or boxes. Most famously, the chimpanzees stacked the boxes to reach an overhead banana. According to Köhler's descriptions, the chimpanzees did not solve the problem through trial and error processes. Instead, after playing randomly with the objects, they came to a solution, apparently instantly, after either regarding the situation or returning to it from another activity. Köhler termed this cognitive problem solving process *Einsicht* in German, or insight. Although Köhler rarely discusses tool use, his chimpanzees were using tools to solve problems.

Köhler's experiments into insight were not the first use of the concept. Awareness of insight in humans goes back to the apocryphal story of Archimedes of Syracuse's discovery of water displacement for measurement of volume while taking a bath. Upon having his "aha" moment, Archimedes was so excited that he ran down the street naked shouting "Eureka!" (Aziz-Zadeh, Kaplan, & Iacoboni, 2009).

About the same time as Köhler was working on Tenerife, Robert M. Yerkes was investigating ideational behavior (or thinking) in monkeys and an orangutan. Yerkes had originally planned to conduct his research on Tenerife until the outbreak of the war interfered. Fortunately he was offered a collection of primates in a facility in California. Yerkes tested if the animals could determine which of a subset of nine doors contained food. Yerkes thought that the orangutan showed learning without trial behavior and that if a human had solved the problem in the same manner, it would be called insight (Yerkes, 1916). In a postscript to The Mentality of Apes, Köhler (1925) stated that after his own research was completed he had received a copy of Yerkes' work and stated that those results agreed with his own.

Insight has been debated ever since Köhler coined the term. The German word *Einsicht* does not necessarily mean insight: a note from Köhler's translator states that the word was translated as both intelligence and insight in the original manuscript. Köhler's own definition was rather vague, intimating that we know what human insight is and the chimps appear to be using the same process (Köhler, 1925). The Gestalt psychologists investigated insight problems; multistep tasks in which only a few of the steps are crucial to the solution and difficult to achieve. To solve the problems, human participants had to change their beliefs about the necessary steps to solve the problem. This belief change was the crucial insight (VanLehn, 1989). This assumption that the solution to a problem is one thing when it is actually something else causes “fixation,” stubbornly refusing to see the problem in a different way. Breaking this fixation is the insight (Mayer, 1995). This has become known as the “Aha” moment, a sudden comprehension that can result in a new interpretation of the problem (Kounios & Beeman, 2009).

Although Köhler never explicity defined insight, Thorpe (1963) later designated a difference between insight and insight learning. He decided that insight referred to perceptual organization and defined it as “the apprehension of relations (p. 100).” Insight *learning* included the animal affecting its situation in response to this new perceptual organization. Thorpe defined insight learning as “the sudden production of a new adaptive response not arrived at by trial behaviour or the solution of a problem by the sudden adaptive reorganisation of experience.” (p. 100) Clearly, Köhler’s problem solving experiments fall under this latter definition.

Since Köhler published his studies, alternative explanations have been advanced for his studies. While not disputing insight, a study by Birch (1963) in 1949, showed that when pulling food with a stick, the chimps needed previous experience with the stick in other situations to show insightful problem solving. In 1949, Schiller (1957) replicated Köhler’s experiments. However, in analyzing the chimpanzees’ performance, Schiller decided that the animals were using purposeless innate motor patterns (seen in play behavior) and solved the problems by chance. Harlow (1949), in his research on monkeys, theorized that the animals had created learning sets. They had learned how to learn, which accounted for the spontaneity of their solutions.

D. O. Hebb, who proposed the theoretical basis for the neuroscience of learning that has come to be known as Hebb's rule (Kandel, 2000), was also interested in insight. Hebb (1949) discussed learning in terms of "phase sequences," temporal arrangements of thoughts and motor elements. For Hebb, insight was a subliminal phase sequence suddenly being consciously perceived. This perception of new relationships, Hebb theorized, "explains how insight depends on experience and yet is not a simple direct result of learning, or the operation of specific habits." (p. 165)

In a study to demonstrate a behaviorist explanation for insight, Epstein, Kirshnit, Lanza, and Rubin (1984) conducted an experiment that also served as a parody of Köhler's study. A pigeon was operantly conditioned in two behaviors: 1) to push a box from one place to another in its cage and 2) to stand on a box situated under a plastic banana and peck at it. The pigeon was placed in the cage with the banana and the box situated on the opposite side of the cage from the banana. The pigeon spontaneously put the two behaviors together and pushed the box over to the banana, stood on the box, and pecked the banana. Epstein (1996) argued that Köhler's chimps are solving their problem by the same process. Moving and stacking boxes are two skills the chimps have naturally learned over their lifetime. In the same way as the pigeon, they are connecting the two skills to achieve the goal. Epstein claims the behaviors are linked through a purely behavioral association called "automatic chaining." However, he admits it may be possible that the solution is arrived at through a purely cognitive trial and error process via covert behavior (Epstein, 1996).

In their study on learning, Gallistel, Fairhurst, & Balsam (2004) found that when examining individual animals of various species across different conditioning paradigms, the animals almost never showed a classic learning curve. The animals reached the asymptote of learning rapidly over one or a very few trials. The researchers posit an information-processing model of learning. The organism gathers information until a decision criterion (threshold) has been exceeded producing the behavior. This learning behavior is remarkably the same as what would be considered insight.

No one doubts that animals *appear* to solve problems by insight, coming to the solution without evident trial and error learning. However, the exact process—whether it is purely behavioral, innate motor patterns, automatic chaining; or a cognitive process, i.e. covert behavior, perceptual trial and error, or the “Aha” moment—is what is debated. Köhler, himself, later stated that his use of the concept of “insight” was not meant as an explanation of the cause of the behavior but as a purely descriptive term (Köhler, 1947).

Nissani (2004, p. 249) has devised seven elements of insightful problem solving:

1. The solution has neither been genetically wired nor acquired by trial and error.
2. Either this kind of problem is new to the animal, or the animal came up with a new solution to an old problem.
3. The correct behavioral sequence has been arrived at suddenly and completely, not in a fumbling, piecemeal fashion.
4. The behavior gives every indication of having been arrived at through a representation of its constituent elements in one’s mind.
5. The action is carried out relatively smoothly, with all its constituent elements purposefully subserving a single goal.

6. The solution is retained after a single performance (Koestler, 1964).
7. The behavior is flexible, the animal able to transfer its abstract rules across a range of physical stimuli (Mackintosh, Wilson, & Boakes, 1985).

Following in Köhler's footsteps, most animal research in insightful problem solving since that time has been done with primates. For example, Beck (1973) found spontaneous cooperative behavior in Hamadryas baboons sharing a tool to attain food. He also found insight in gibbons solving a string pulling problem (Beck, 1967). In research with orangutans (Mendes, Hanus, & Call, 2007), the animals solved a problem in which a peanut was at the bottom of a long thin tube. The orangutans retrieved the peanut by spitting water into the tube until the nut was within reach.

Other taxa have also been tested for insight. Tolman and Honzik (1930) found that rats were capable of navigating mazes to find food much more quickly after having had non-reinforced opportunities to explore. He initially attributed this capability to insight. He later reframed this and devised his theory of latent learning and cognitive maps (Tolman, 1948).

Research into insight has also been conducted with birds. The string pulling test is a task that has been used to investigate insight in birds (Heinrich, 1995). In this test, a bird has to pull up food dangling from a string through a number of steps of standing on the string and pulling on it repeatedly until the food is within reach. Because of the difficulty of completing the task purely through trial and error, the test is posited to indicate insight. A number of bird species have completed this task including corvids (ravens) (Heinrich & Bugnyar, 2005) and keas (parrots) (Werdenich & Huber, 2006). New Caledonian crows, a naturally tool using species, have shown advanced abilities in problem solving, bending wires to make tools to get food placed out of reach (Weir, Chappell, & Kacelnik, 2002). Rooks, a naturally non-tool using bird, have substantiated an Aesop's fable by spontaneously solving the problem of acquiring a worm floating out of reach in a container of water. The birds dropped rocks into the water to raise the water level and attain the food (Bird & Emery, 2009). In an example of meta-tool use, a New Caledonian crow pulled a short stick up from a string, to reach a longer stick in a cage, to get food placed in a container (Taylor, Elliffe, Hunt, & Gray, 2010).

There are anecdotal tales of elephants exhibiting insight. For example, Romanes (1882) tells of an elephant that chased some people up a tree. In order to get to the people, the elephant carried a number of logs to the tree and stacked them so that he could climb up to reach his quarry that were, fortunately, still out of reach. However, there has been little experimental evidence for insight in elephants. Hart, Hart, and Pinter-Wollman (2008) state that elephants perform rather poorly in insightful problem solving tasks. In unpublished research of their own, they found that elephants never used tools to obtain food that was otherwise out of reach. The elephants had previously learned to eat from a tilting platform but when it was placed out of reach they never used available sticks to tilt it down.

Nissani (2006) has run several studies of problem solving in elephants but claims no evidence for insight. In an experiment adapting a string-drawing paradigm from bird studies, a rope was attached to an elastic bungee cord. The rope was baited with food that the elephant could get by pulling on the rope and securing it in some manner so the rope did not snap back, pulling the food back out of reach. Both elephants tested solved the problem, though not in a manner consistent with insight. One of the elephants pulled the rope in the same manner, whether or not she was engaging in the problem. Neither elephant performed the task in a complete and smooth manner, nor retained the skill after one successful trial.

In another study, elephants were trained to remove lids from buckets to obtain food rewards. If the lid was removed from the bucket and placed next to it, the elephant still lifted the lid before getting the food. Nissani (2006) interprets this result as showing a lack of causal reasoning; however an alternate explanation may be that the elephants, being extremely well trained, were performing exactly the previous training.

Overview of Research Goals

Considering the apparent disparity between elephants' cognitive abilities and their failure to show insightful problem solving, my research sought to further investigate problem solving in Asian elephants. I conducted ten experiments using the three elephants resident at the Smithsonian National Zoological Park in Washington, D.C. Experiments 1-4 were conducted in the interior of the elephant house. Experiment 1 was a brief replication of Irie-Sugimoto, et al.'s (2008) study of means-end behavior in elephants. Cardboard trays with food placed on one end were positioned outside the bars of the elephant's stalls. To obtain the food, the elephants needed to pull the tray toward them, showing understanding of the means-end relationship. In Experiment 2, the trays were placed out of reach of the elephants' trunks. This study investigated if the elephants would use tools to pull the trays closer to attain the food. Experiment 3 investigated if elephants would use a tool in a more ecological task. An artificial "tree" was placed outside the bars of their stalls with fruit out of reach on one of the branches. This experiment tested if the elephants would use a stick to knock the fruit out of the artificial tree and into reach. Experiment 4 tested if the elephants were capable of an insightful chain pulling task adapted from Köhler (1925) similar to string pulling tasks in birds.

Experiments 5-10 were conducted in the yard outside the elephant house. Experiment 5 investigated if the elephants would use a different style of tool, a movable platform, to reach food placed overhead and out-of-reach. Experiments 6, 7, and 8, built on this concept to test if the elephant would generalize this ability to other positions and objects. Experiment 9 tested if the use of a stick as a tool was affected by the goal of the task, specifically if the reinforcement involved was food or manipulating a non-food enrichment object. Experiment 10 examined social learning by having one elephant demonstrate the solution to a tool use problem while a second elephant observed. The second elephant was then presented with the same test to determine if she solved the problem by a similar method. Overall, this research investigated the parameters of problem solving through tool use in elephants.

Chapter 2: General Methods

Subjects

We tested three Asian elephants *(Elephas maximus*) currently housed at the Smithsonian National Zoological Park (NZP), Washington, D.C. The group was composed of:

Ambika, a female, approximate date of birth – 1/1/1948, approximate weight - 3240 kg. She arrived at National Zoological Park in 1961. Ambika was captured in the Coorg Forest, India at about 8 years of age. She was trained and used as a work elephant for about 2 years before coming to the U.S.A. and has lived with multiple other elephants including Shanthi at NZP until 1/25/2006. Ambika has lived exclusively with Shanthi and Kandula since then. Her dominance to Shanthi varies. At times she is submissive and at other times dominant. Ambika dominated Kandula at the time of experimentation. She had multiple trainers until 1987 and since then Ambika has been handled with greater consistency. At the time of experimentation, she was handled using both free and protected contact (National Zoological Park Records, 2010).

Shanthi, also female, approximate date of birth – 1/1/1976, approximate weight - 4050 kg. She arrived at NZP 12/30/76. Originally from Sri Lanka, Shanthi was found in a well at approximately 3 months of age and raised in a Sri Lankan elephant orphanage. She lived with multiple elephants including Ambika at NZP until 12/5/2006. From 3/1991 until 11/1992, Shanthi was moved to Burnet Park Zoo, Syracuse, NY for breeding. There she resided with 2 male and 3 female Asian elephants. Since 1/25/2006, she has lived exclusively at the National Zoo with Ambika and Kandula. As with Ambika, Shanthi's dominance with the other female varies. She had multiple trainers until 1987 and since then Shanthi has been handled with greater consistency. At the time of experimentation, she was handled using both free and protected contact (National Zoological Park Records, 2010).

Kandula, a male, was born 11/25/01 at NZP through artificial insemination of his mother, Shanthi, by Calvin (currently at Ostrava Zoo, Czech Republic). Kandula’s weight at the time of research was ~2250 kg. He has lived with his mother since birth. Besides Ambika and Shanthi, Kandula has lived with one other elephant, Toni, an Asian female, until her death at 41 years of age on 1/25/2006. Since then he has lived only with his mother and Ambika. Kandula began serious interest in food reinforcements for training about 6 months of age. He was handled via free contact primarily for the first two years, gradually learned to perform all behaviors in protected contact by the age of three. All staff interactions with Kandula are through protected contact (National Zoological Park Records, 2010).

All animals were maintained under their normal NZP care and feeding protocols. No animals were food deprived for the purposes of this study. All food rewards were supplemental to their daily feeding requirements. The handling of the elephants during the study was conducted by NZP elephant staff.

All three elephants have been extensively trained by the elephant keeping staff in a number of behaviors for husbandry and demonstration purposes. See Table 1.

Ethics Statement

All experiments were reviewed and approved by the Institutional Animal Care and Use Committee of Hunter College, City University of New York (Approval #DR-insight 6/11-01), decision reviewed and accepted by the Smithsonian National Zoological Park.

Table 1

List of commands, behaviors, and elephants trained.

Command	Description	Elephant
All right	release from previous command	All
At ease	trunk at rest, straight down	All
Back	move back in a straight line	All
Blow	exhale forcefully through trunk	All
Bow	bend left wrist back and touch it to the ground with trunk up	All
Bring	bring object being held to handler	All
Corners	raise opposite front and rear legs	Ambika, Shanthi
Crawl	move forward in either the stretch or kneel positions	Kandula
Cross	cross left legs in front of right legs	All
Down	lateral recumbency	All
Ears	present ears forward	All
Foot-on front leg	wrist to elbow parallel to ground	All
Foot-on rear leg	foot to knee parallel to ground	All
Give	hand object to handler, hold it until taken	All
Half	half way between stretch and down	All
Harness	lower head for harness	Ambika, Shanthi
Head	lower head while front feet are extended out	All
Here	move designated body part towards handler	All
Hold	do not release grip (with mouth or trunk)	All
Kneel	down on front wrists	Kandula
Leave	drop whatever is in trunk, or don’t touch	All

Table 1 (continued)

List of commands, behaviors, and elephants trained.

Command	Description	Elephant
Lift	front foot raised as high as it can go, pad up, slightly outward, rear legs tucked	All
Move	move forward in a straight line	All
No	stop unwanted behavior	All
Open	open mouth for tooth inspection	All
Over	move away	All
Pad	front foot bent back at wrist, pad showing	All
Pick	lift an object with trunk	All
Place	stay in a designated area	All
Push	push object with head	Ambika, Shanthi
Put it away	put tire on top of bars	Shanthi
Relax	relax trunk muscles for handler manipulation	All
Salute	on rear knees with left front leg raised with trunk up	All
Same	raise both legs on same side of body	All
Shake	shake head	Ambika, Kandula
Side	touch mid section of body to target	All
Stretch	sternal recumbency	All
Tail	grab tail of another elephant,	All
Also:Tail	touch base of tail to target	All
Touch	touch trunk to handler hand or target	All
Trunk	curl trunk up to touch forehead	All
Tub	climb onto object - stump or balance beam	All

Table 1 (continued)

List of commands, behaviors, and elephants trained.

Command	Description	Elephant
Steady	freeze	All
Turn	move from a center axis pivot	All
Wait	do not proceed (Only for calves or elephants not yet trained to steady, a transition to place or steady)	All
Wiggle	flap ears	Shanthi

Facilities

Elephants were housed in indoor and outdoor areas of the NZP Elephant House. The indoor facilities consisted of 6 stalls 7.9 m across with walls on three sides and vertical bars facing the public area. About 3.7 m from the bars was a 1 m high railing, which separated the public from the animal area. The floor of the elephant stalls was raised 0.8 m above the floor of the public area outside the enclosure. Sliding doors permitted and restricted access between stalls and the adjacent outside yard. Items such as tires and loops of fire hose were hanging in the stall as part of the elephants' daily enrichment. All experimental sessions conducted in the interior of the elephant house, Experiments 1-4, were conducted in the same stall (the third stall). The position of this stall relative to the others enabled elephants not involved in testing to be placed in a stall out of view of the session.

Experiments 5-10 were conducted in the exterior yard of the elephant house. This yard consisted of two adjoining yards separated by a fence that is open on either end, measuring 24.4 m x 25.9 m. This yard also adjoined a larger yard separated by a large motor operated gate that was closed during sessions. There were two trees within the yard, as well as trees bordering the yard. Within the yard was a large bathing pool as well as enrichment items that were offered daily as part of the zoo's enrichment program. The public had a view of this yard at the opposite side from where experimental sessions were conducted. See Figure 16 for photo of yard. The elephant facilities have been substantially enhanced since the completion of this study.

General Procedures

The first four experiments in the interior of the elephant house were means-end comprehension, the tray pull problem, the tree problem, and the chain problem. The elephants were tested individually and sessions lasted 20 minutes. The following six experiments, conducted in the exterior elephant yard, were tool use, tool displacement, tool generalization, stacking, trunk held object use towards food vs. objects, and social learning. Kandula was tested individually for 20-minute sessions. Initially, Shanthi and Ambika were tested individually for 20-minute sessions. It was then decided that it would be less stressful for the elephants if they were tested together and sessions could be extended to 30 minutes. Specific procedures for each experiment are discussed in the following chapters.

Data Collection

During the sessions conducted in the interior of the elephant house, observations and data collection were conducted via a video monitor from behind a curtained blind placed ~3 m from the testing stall in front of an adjacent stall. For the exterior sessions, experimenters were positioned on the roof of the elephant house overlooking the elephant yard for both observing the experiment and the placement of food. All sessions were videotaped using a Canon HV20 hi-definition digital video camera.

Data Analysis

Behaviors were coded on computers from the video recordings according to predetermined ethograms using the SubTrak Video Coding Program for Observational Research (Takach, Lindtvedt, & Ragir, 2006). Behavior was coded by myself and three student volunteer research assistants. I trained the research assistants to a gold standard, and supervised and affirmed consistency in all behavior coding. Specific details are provided for each experiment in the following chapters.

Chapter 3: Problem Solving in Elephants

Research into problem solving can serve as a valuable method to investigate mental processes in different species (Sheerer, 1963). Köhler (1925) conducted seminal research into the problem solving abilities of our closest relatives, the great apes. In several of his experiments, Köhler would place food out-of-reach outside the bars of the chimpanzee enclosure. The chimpanzees were provided with items that could be used as tools to draw the food closer. Köhler happened upon this paradigm from reports from Teuber, his predecessor at the ape research station. Teuber had seen one of the chimps trying to get food on the other side of the bars. Unable to reach it, the animal searched about the enclosure, stumbling upon a shoe-scraper made of wood and metal bars. The chimp took the object apart, acquiring one of the bars and used it to drag the food in closer. Köhler adapted this paradigm to a number of tests. First, he put the food out of reach without supplying sticks. The chimps removed branches from a bush and used those to get the food. Eventually, Köhler supplied the chimpanzees with sticks that allowed them to get the food. He also provided them with two shorter sticks that could be inserted into each other to create a longer stick. The chimpanzees also solved this problem (Köhler, 1925).

Variations of this task, using sticks or other items as tools to rake in out-of-reach food items, has since become a common task to test insightful problem solving abilities in non-human animals. Later researchers continued Köhler’s chimpanzee research (Jackson, 1942), finding variations in problem solving abilities along with age effects: the performance of the older apes appeared more insightful. More recent research has shown that chimpanzees understand the qualities of the tool that enable the task, for example, choosing a rigid rake over a flimsy one (Furlong, Boose, & Boysen, 2008). Other primates have also been tested using this method, including gorillas (Yerkes, 1927), macaque monkeys (Hihara, Obayashi, Tanaka, & Iriki, 2003), baboons, (B. B. Beck, 1973) and tamarins (Hauser, 1997). Neuropsychological research has provided insights into neural correlates during tool use. For example, one study in macaques measured receptive fields during the use of a tool that extends arm reach. The researchers reported that during this type of tool use, the brain incorporates the tool into the neurological representation of the body, in essence, lengthening the arm (Maravita & Iriki, 2004).

I conducted a series of experiments on the abilities of elephants to understand means-end contingencies and the use of tools for problem solving. Three experiments were conducted inside the elephant house in which each elephant was tested individually in means-end comprehension, obtaining fruit on an out-of-reach tray, and obtaining fruit from an out-of-reach branch. The enclosures in the old elephant house with their barred fronts seemed ideal for running experiments in which the elephants could use sticks to pull food into reach.

Experiment 1: Means–End Comprehension

In the first experiment, it was necessary to determine if the elephants were cognizant of the properties of the means-end relationship that pulling one end of a tray would bring food placed on the other end of the tray closer. This experiment was a pseudo-replication of research done by Irie-Sugimoto, Kobayashi, Sato, & Hasegawa (2008). This research examined means-end cognition in elephants.

First studied by Piaget (1952), as a step in the development of human children, the means-end relationship has also been studied in animals. Piaget tested children to see if they understood that pulling on one end of a towel with a toy sitting on the other end would bring the toy closer. They showed recognition of this relationship at about eleven months old. Hauser, Kralik, & Botto-Mahan (1999) showed that tamarins were aware of the means-end relationship in drawing items closer by choosing pieces of cloth on which food sat as instead of cloth that was separated in the middle or placed next to the food. Irie-Sugimoto, et al. (2008) replicated this research in elephants. They showed that the elephant chose a tray with food on one end over a tray with food that had a separation in the middle or a tray with the food placed next to the tray.

In Experiment 1, I tested if the elephants were capable of understanding that they could pull a tray forward to obtain the food at the other end, indicating an understanding of the means-end relationship.

Subjects

Ambika, Shanthi, Kandula.

Methods and Materials

Facility. Interior of the elephant house.

Materials and Procedure. A rectangular cardboard tray, 0.91 x 0.46 m with a 6.54 cm side, was constructed with pine boards at the narrow ends. This tray was chained to the public railing so that it could be slid on the floor up to the edge outside of the elephant stall.

Prior to the beginning of the experimental sessions, the reach of each elephant’s trunk through the bars was measured by placing pieces of food progressively further away on the floor until it was ascertained that the elephant could no longer reach the food. Due to the differential floor levels between the stall and the area on the opposite side of the bars beyond the stall, the elephants had to reach through the bars of the stall downward and outwards to reach the tray.

Sessions began when the elephant entered the stall. Experimental sessions lasted 20 minutes. Trials were determined by completion of the task, i.e. pulling the tray forward and retrieving the fruit. A criterion of 10 trials in a single session was set. All experimenters were out of view either by being situated out of sightlines of the subjects or behind curtained blinds so as to avoid inadvertent cuing.

The tray was placed outside the bars of the stall on the floor with its nearer edge just within reach of the elephant's trunk. Pieces of either honeydew or cantaloupe melon were placed on the opposite end of the tray from the elephant. If an elephant pulled the tray toward it and retrieved the fruit, the tray was pulled back by the experimenter using the chain, the melon was replaced and the tray was pushed back into position with a pole.

Results and Discussion

In the initial trial of the first sessions conducted with Ambika and Shanthi, both females pulled the tray toward them without exhibiting trial and error efforts. Both reached criterion in their first session. A second session was run with each elephant to confirm the results. Figures 1-4 show the latency between the placement of the tray and the acquisition of the food reinforcement for each successful trial for each elephant. Trials in which the elephants pulled the tray but did not successfully obtain the food are not included. The extreme latency (5 min 40 s) in Session 1, Trial 8 for Shanthi reflects an episode of stereotypical swaying. Shanthi exhibits this stereotypical behavior and engages in it occasionally for long periods of time. Both females exhibited an understanding of the means-end relationship.

It was difficult to assess this ability in Kandula due to his neophobic tendencies. Initially Kandula appeared to be afraid of the apparatus and moved away from the bars of the enclosure. He was desensitized to the tray by placing small pieces of food progressively closer to the tray without having him pull it. However, he did pull the tray in the first session and obtained the food but appeared frightened by the noise of the chain during his initial attempt. To address this problem, the chain was covered in cloth hosing to reduce the noise. After these modifications, Kandula reached criterion by his 4th session (Figures 3 and 4). It may be argued that in this experiment, Kandula was exhibiting tray pulling behavior due to reinforcement he received for pulling the tray during the desensitizing procedure.

Irie-Sugimoto, et al. (2008) conducted a series of experiments with various forms of trays and placements of food to test the understanding of the mean-end relationship in elephants. Their research provides extensive evidence for means-end comprehension in elephants. For this research, establishing that the elephants were capable of pulling the tray to obtain food in Experiment 1 was a necessary step for the tray pulling problem in Experiment 2.

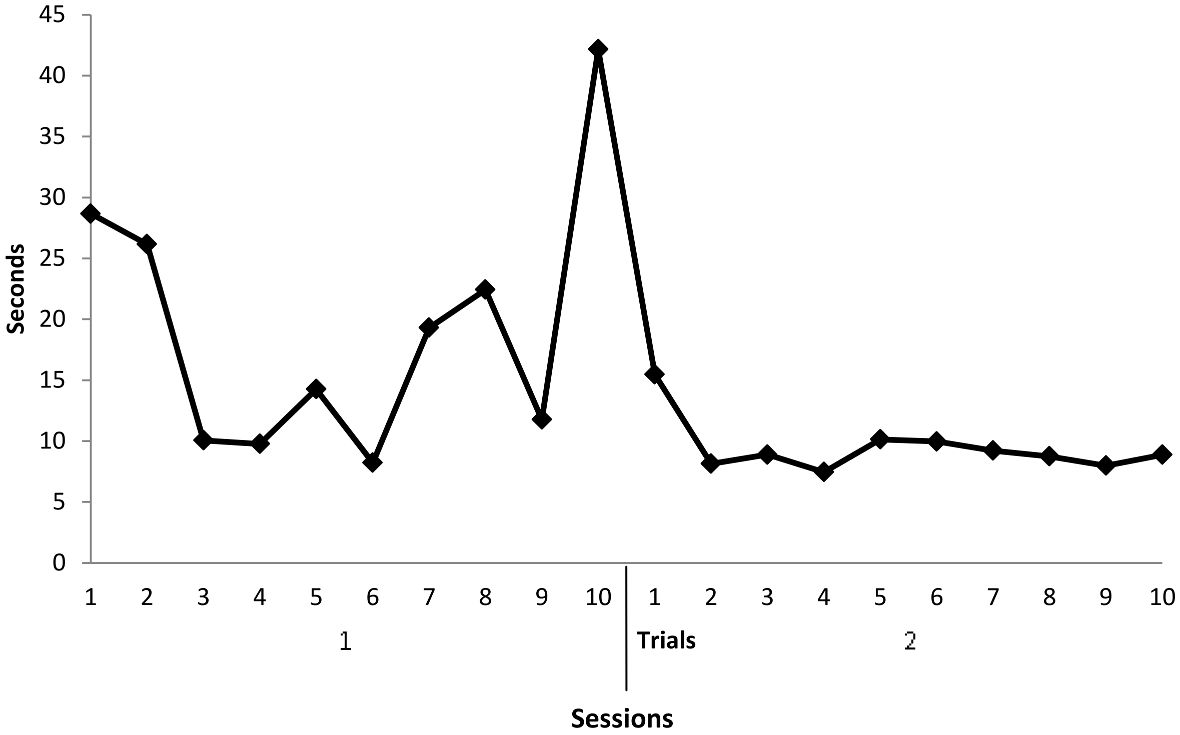

Figure 1. Means-end testing in Ambika. The figure shows the latency in Ambika's responses when presented with food tray. Latency is shown between the placement of the tray and acquisition of reinforcement for two sessions, ten trials in each session.

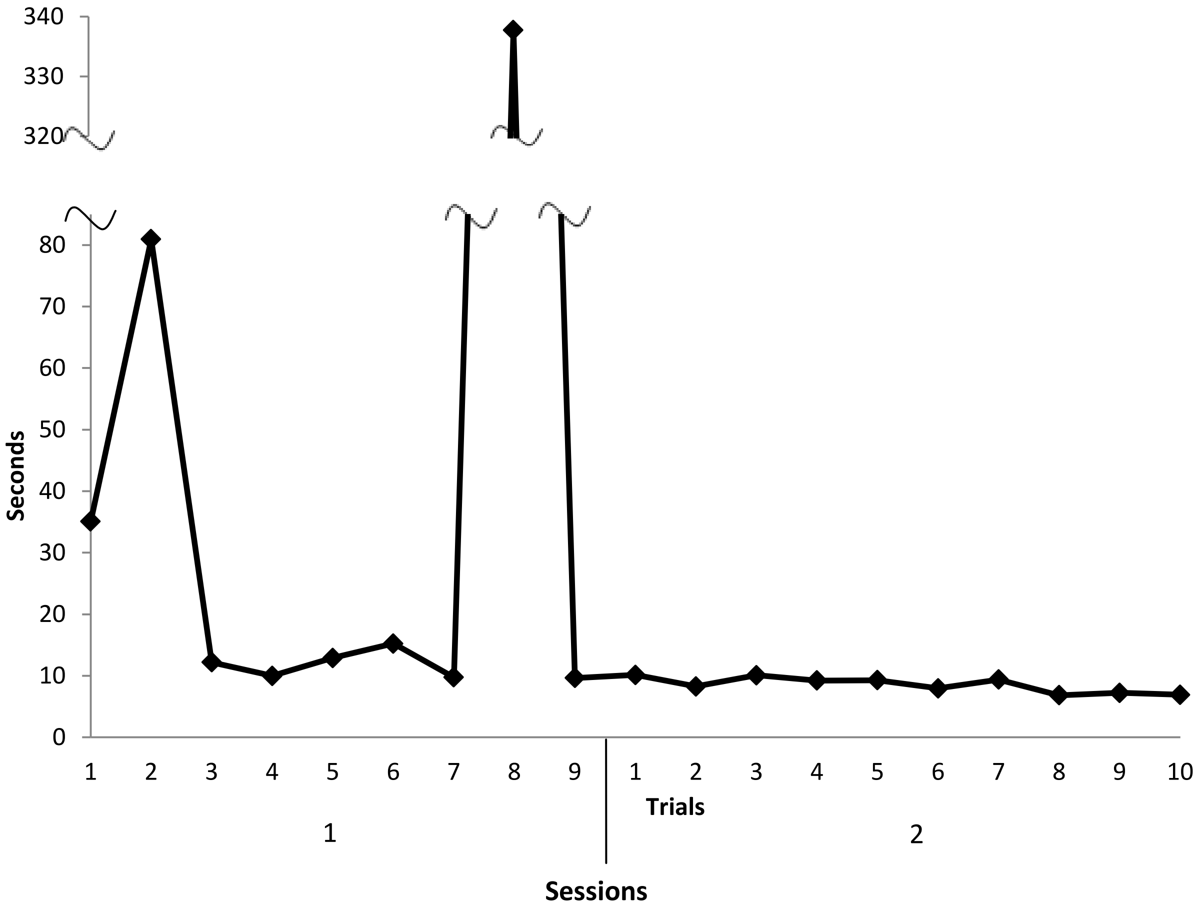

Figure 2. Means-end testing in Shanthi. The figure shows the latency in Shanthi's responses when presented with food tray. Latency is shown between the placement of the tray and acquisition of reinforcement for two sessions, 9 trials in the first session and 10 trials the second session.

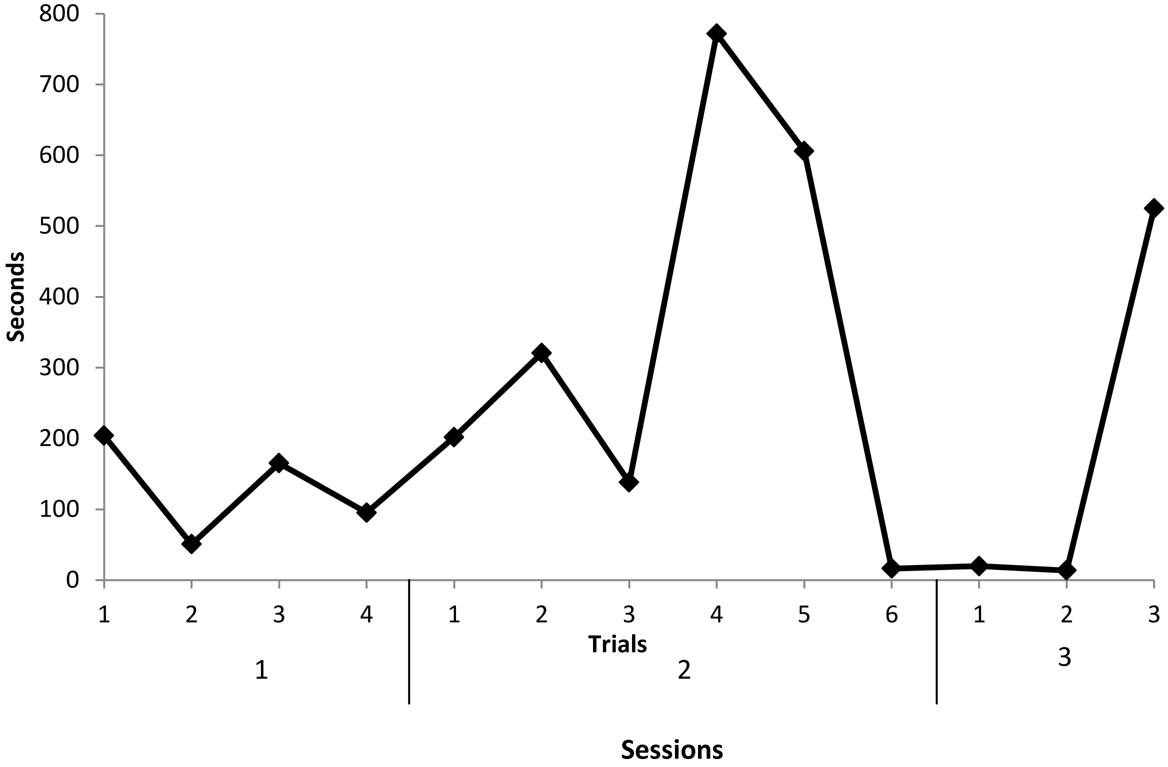

Figure 3. Means-end testing in Kandula, sessions 1-3. The figure shows the latency in Kandula's responses when presented with food tray. Latency is shown between the placement of the tray and acquisition of reinforcement for three sessions.

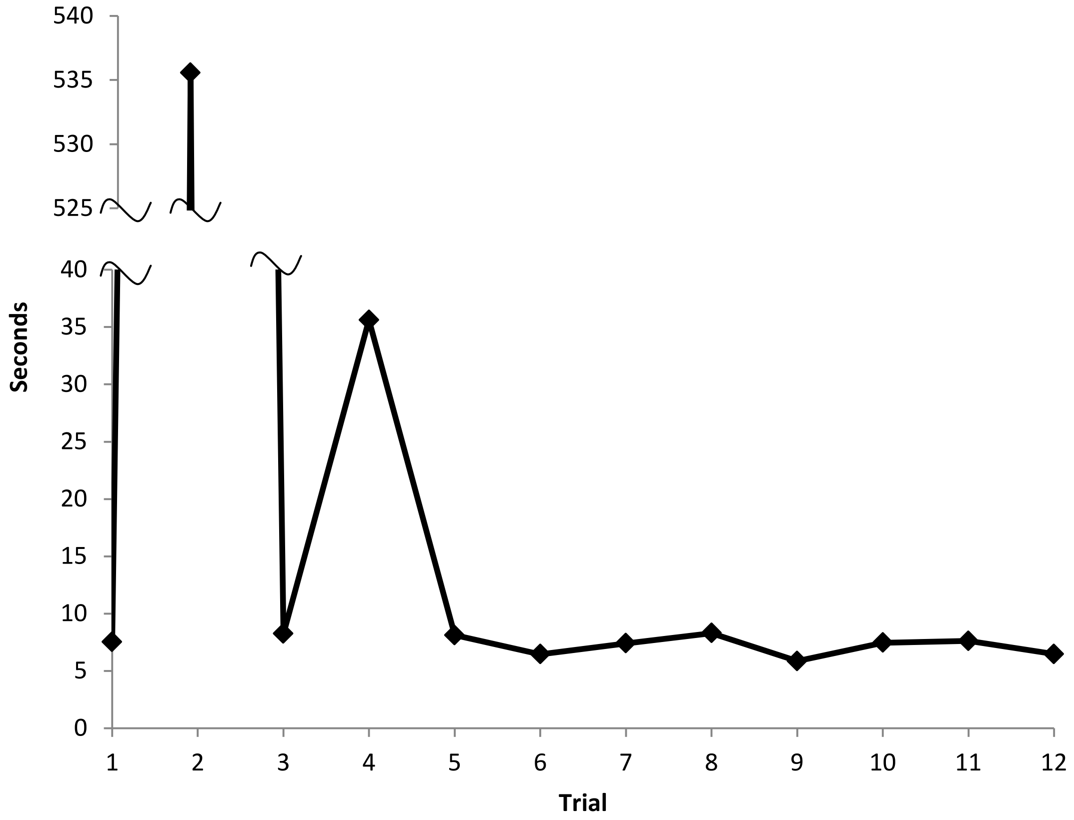

Figure 4. Means-end testing in Kandula, session 4. The figure shows the latency in Kandula's responses when presented with food tray. Latency is shown between the placement of the tray and acquisition of reinforcement for Kandula's fourth session.

Experiment 2: The Tray Pull Problem

One common problem presented to animals tests if they are capable of using a stick as a tool to pull otherwise out-of-reach food closer. This paradigm has been in use since Köhler's (1925) research on great apes. Raking in food with a stick has also been tested in a number of other species, particularly birds. Variations of the test have been used with New Caledonian crows (Taylor, et al., 2010), rooks (Seed, Tebbich, Emery, & Clayton, 2006), and blue jays (Jones & Kamil, 1973). Even a rodent, a degu, has been trained to draw food in with a rake-like tool (Okanoya, Tokimoto, Kumazawa, Hihara, & Iriki, 2008).

Experiment 2 was conducted to investigate whether the elephants were capable of this type of problem solving through tool use, the use of a stick as a rake. Food was placed out of the elephants' reach on the opposite side of the bars of their stall and sticks (potential tools) were provided within trunk reach.

Subjects

The same three elephants in Experiment 1, Ambika, Shanthi, Kandula, were the subjects of this experiment.

Methods and Materials

Facility. Same as in Experiment 1.

Materials and procedure. The same tray was used in the same configuration as Experiment 1. Three 1.85 m lengths of bamboo were also provided. Bamboo sticks were used because they are a daily part of the elephants' diet and therefore posed no danger to the animals. Also, they are not novel enough to be preferred over the food in the tray nor were they likely to be immediately consumed. See Figure 5.

Sessions began when the elephant entered the stall. Experimental sessions lasted 20 minutes. Trials were determined by completion of the task, i.e. pulling the tray forward with the bamboo stick and retrieving the fruit. A criterion of 10 trials in a single session was set.

For the first trial of each session, the tray holding a piece of melon was placed on the floor just within the reach of the elephant's trunk prior to the beginning of the session. This first reachable fruit was provided to maintain the elephants' interest in the task from session to session. After the elephant pulled the tray, it was replaced just out of reach along with three bamboo sticks that were placed within reach. During the session, the tray was placed in position with a long pole held by an assistant from behind a blind. Trays were attached to a chain that enabled them to be pulled and removed by the same hidden assistant. All efforts were taken so that the elephant would not see the experimenters during testing to avoid inadvertent cueing of the animals. In the last two sessions, the amount of melon was doubled from a single half to two halves.

Figure 5. Photo of experimental set up showing tray in place with bamboo sticks.

Results and Discussion

Nine sessions were conducted with Kandula and Ambika, 10 sessions were conducted with Shanthi. All elephants attempted to reach the food with their trunks. The elephant’s interest in the tray was indicated by either pointing their trunk towards the food to sniff it or stretching their trunk towards it (Figure 6). At no time did any of the elephants reach for the tray with a stick nor manipulate the sticks outside the bars of the stall. All three elephants reached for the sticks and pulled them through the bars into the stall. While they ate some of the bamboo, breaking it into smaller pieces, there was always at least one complete stick left at the end of the session. All of the elephants were very manipulative, using the sticks in many tool-like ways within the stall. They beat on the walls and floor, hit hanging enrichment items, scratched themselves and used the sticks in prying motions on the doors. (See Appendix). The only use of a stick outside the bars happened when Kandula, in apparent frustration at being unable to reach the food, threw a short piece of bamboo in the direction of the tray.

Based on this lack of success, it was decided that perhaps pulling a tray with a stick was an unnatural and/or difficult movement for an elephant. A more ecological task was devised for the next round of experimentation.

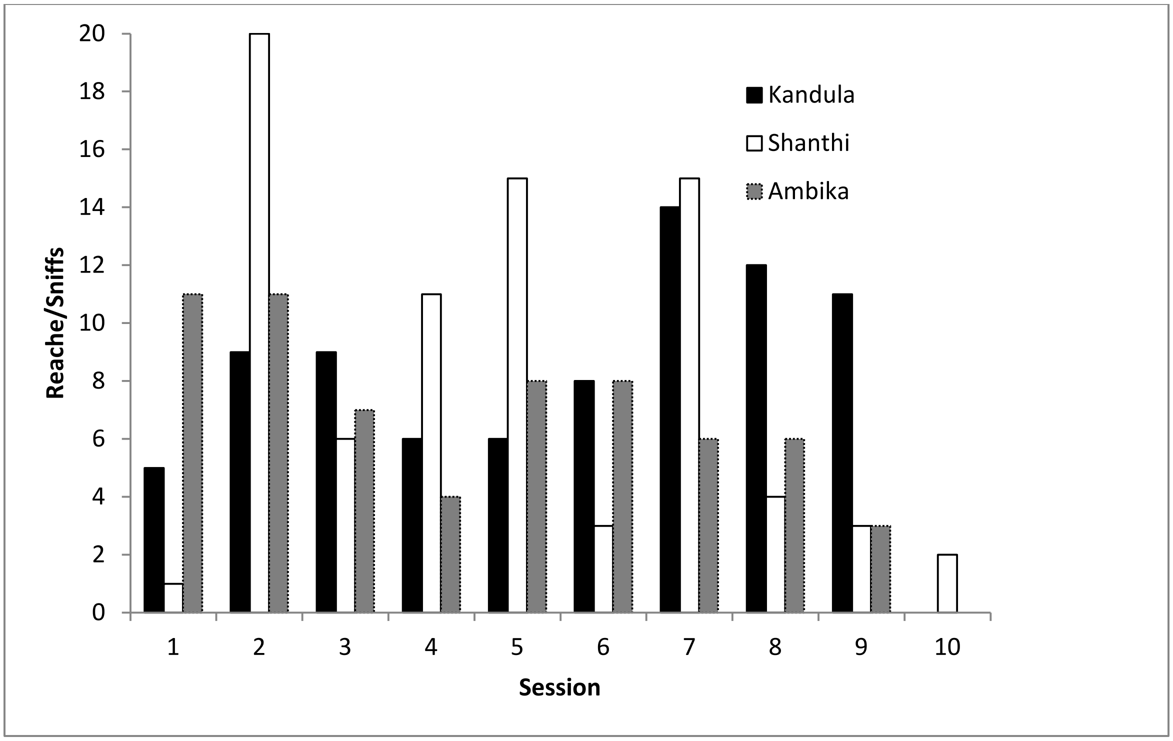

Figure 6. Interest in food in Experiment 2 shown by number of times the elephant either sniffed (pointing trunk towards food in an apparent effort to smell it) or reached for the food for each elephant in each session. Session 10 was only conducted with Shanthi..

Experiment 3: The Tree Problem

To provide the elephants with a problem-solving task that was more ecologically valid, I designed an apparatus that would present the elephants with a situation in which they would have to knock fruit out of a tree with a stick as opposed to pulling a tray towards them. An artificial tree apparatus was designed and presented to the elephants just beyond the bars of their indoor enclosure within the elephant house. The tree was designed with three branches, 2 within the elephants' trunk reach and one higher branch, baited with food, beyond trunk reach. Each elephant was provided with sticks outside of their enclosure, as well as the removable tree branches, within their trunk reach that could serve as tools to reach or knock down the baited branch.

Subjects

The same three elephants in Experiment 2, Ambika, Shanthi, Kandula, were the subjects of this experiment.

Methods and Materials

Apparatus. An artificial "tree" was constructed using a 3.66 m length of PVC pipe, 15.24 cm in diameter. The pipe was attached vertically by elastic cords to the railing which separated the enclosures from the public area. The tree was 2.7 m from the stall bars.

Holes were drilled in the pipe to loosely hold 3 lengths of bamboo. The two lower lengths of bamboo were parallel to the ground, reachable by the elephant from the cage. One stick had melon affixed to the end by inserting the stick into the melon. The uppermost hole was drilled so that the bamboo sat at an upward angle, out of the elephant's trunk reach, but could be knocked into a slot. This action would bring the fruit within the elephant's reach. The exact distance for each fruit varied due to the different length of each elephant's trunk. See Figures 7a and 7b.

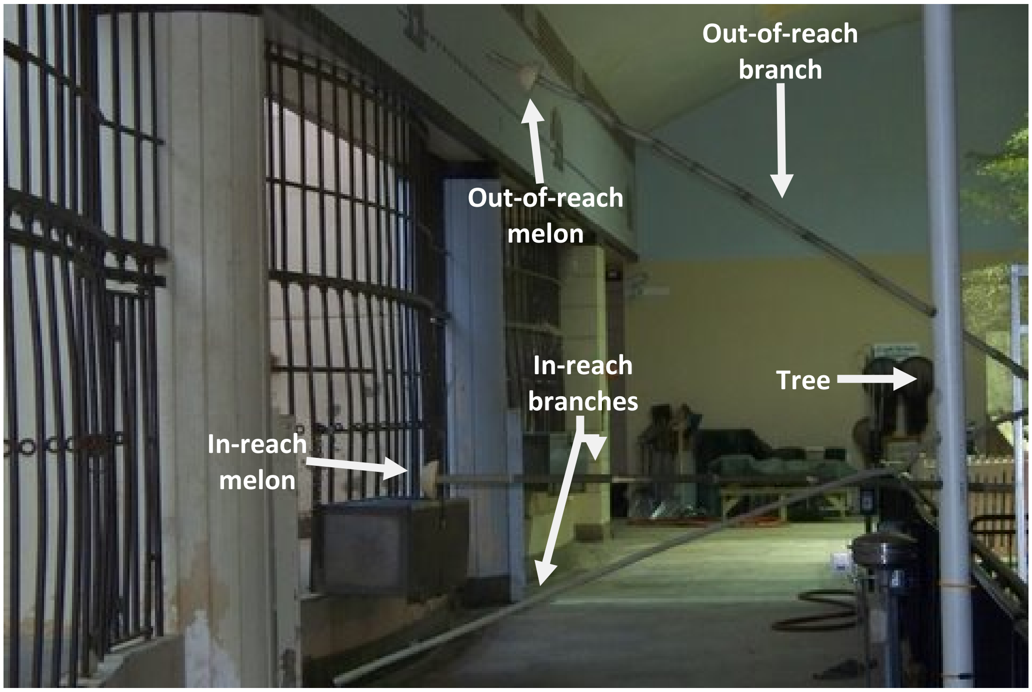

Figure 7a. Photo of the “tree” (far right in image).

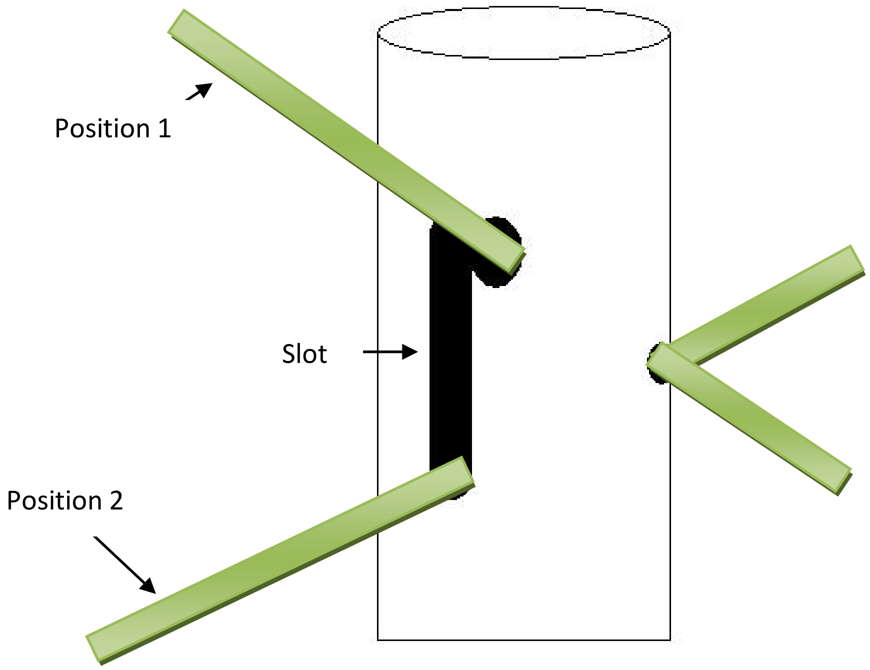

Figure 7b. Diagram of the hole for upper branch. Branch with out-of-reach fruit is initially placed in position 1. If the branch is hit with a stick, it falls into the slot into position 2 bringing the fruit within reach of the elephant.

Procedure. The elephants were tested individually. Sessions began when the elephant entered the stall. Experimental sessions lasted 20 minutes. Trials were determined by completion of the task, i.e. knocking the fruit into reach and eating it. A criterion of 10 trials in a single session was set. All experimenters were placed out of view either by being out of sightlines of the subjects or behind curtained blinds so as to avoid inadvertent cuing.

The "tree" was preset in position when the elephant entered the stall. Two bamboo sticks were placed within reach on the tree that could be removed by the elephant. One had a piece of melon on the end. Two sticks were also placed on the ground within reach. The upper stick on the tree was set at an angle, out of reach. If the elephant knocked the branch lightly with another stick the fruit and branch would fall within reach.

Results and Discussion

Eleven sessions were conducted for each of the three elephants. In the initial trial of each session, the upper baited branch was placed within reach, so the elephants could knock it down with their trunk to see how it operated and obtain the fruit. All the elephants acquired fruit in this manner. In subsequent trials, the baited branch was placed out-of-reach. If they hit the branch it fell into the slot and the fruit was then within reach. As in Experiment 2, none of the elephants completed a successful trial. At no time did they attempt to knock the fruit down using the sticks. As in Experiment 2, all elephants attempted to reach the food to varying degrees. Kandula showed the most interest in the food, followed by Shanthi and Ambika (Figure 8). Shanthi appeared to have lost almost all interest after Session 6. Kandula exhibited a behavior that I termed a "frustration bounce." After exerting effort in reaching for the fruit, he moved his head up and down repeatedly, hitting the horizontal bar of the stall with the dorsal side of his trunk near his mouth. He exhibited this behavior between 1 and 6 times in each session starting with the Session 2. Notably, the elephants did obtain the sticks that they acquired from both from the floor and the tree and pulled them into the stall and manipulated in the same manner as in Experiment 2.

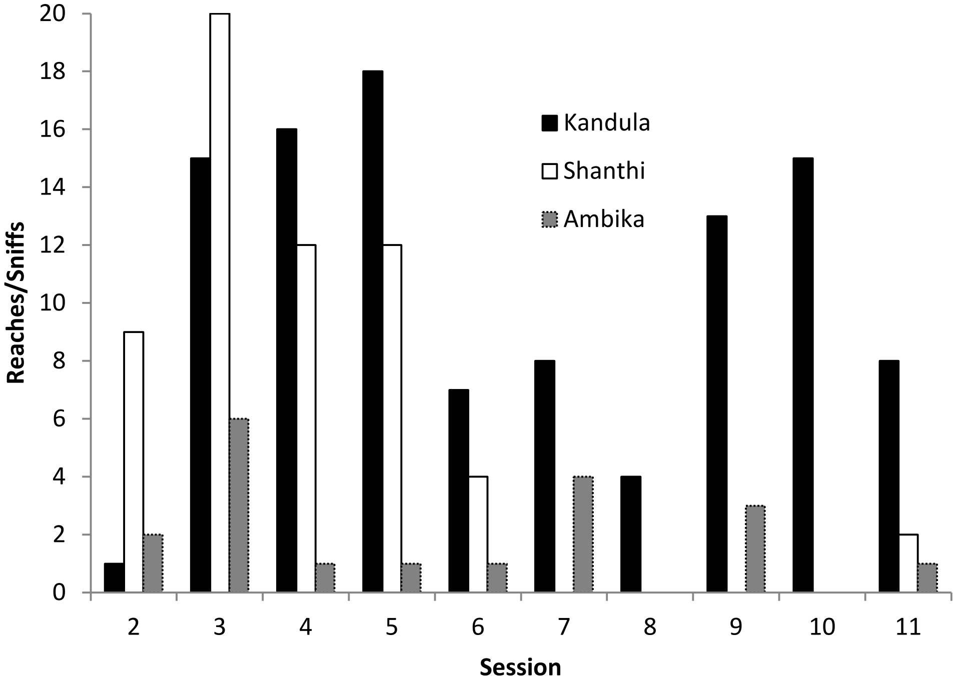

Figure 8. Interest in food in Experiment 3 as shown by number of times the elephant either sniffed (pointing trunk towards food in an apparent effort to smell it) or reached for the food for each elephant in each session.

These results lead to an important question: if the elephants use the sticks in tool-like ways within the cage, why do they not attempt to get the fruit with the sticks? They showed interest in obtaining the fruit, on some occasions struggling with great effort to reach it. They demonstrate the capability of manipulating the sticks as tools but never even attempt to use them to acquire food.

In their review of tool use in wild and captive elephants, Chevalier-Skolnikoff and Liska (1993) found many examples of tool use behavior, both experimental and anecdotal. In literature reviews, both they and I have found only one instance of an elephant using a stick as a tool to acquire food: at the Berlin Zoo in 1930 Graf Zedtwitz (1930) reported that their "Congo dwarf elephant" named Mampe used a stick held in its trunk to reach for bread and other food on the grass outside the bars of its cage. Zedtwitz compares the elephant's tool use to that observed in Köhler's chimps. This account appears to be the sole instance reported of an elephant using a tool to obtain food. The rarity of this one particular type of tool use, which seems easy enough for an elephant to accomplish, raises the question of why an animal with these advanced manipulative and cognitive abilities would not use a tool to gain food.

Rather than being a cognitive deficit as Hart, Hart, & Pinter-Wollman, (2008) posited, I theorized that that the deficit is perceptual. According to this theory, the multi-sensory characteristics of the trunk are responsible for the elephants' refusal to use a stick held in its trunk as a tool for acquiring food. While the elephant is capable of seeing the food, it relies on its two primary foraging senses, smell and touch, to investigate the food item before eating it. However, if the elephant is holding a stick, it loses both of these senses because the elephant's trunk is wrapped around the tool. The elephant would normally use its sense of smell to locate food, but holding the tool requires that the trunk is facing away from the food. The tip of the trunk may even be closed, blocking its sense of smell entirely. Reaching out with the stick also blocks the extremely sensitive tip from feeling and investigating the food. The situation is analogous to a person whose eyes are in the palm of their hand (similar to a creature that appeared in the film “Pan’s Labyrinth” (Del Toro, 2006)). If this creature were to decide to pick up a tool to obtain an object, the action of wrapping its hand around the tool would blind it, losing its primary sense - vision. Rasmussen (2006) describes the trunk tip as a “refined eating tool.” The elephants, when holding a stick in their trunk, lose both of their primary senses – olfaction and touch. The integration of these senses in a manipulable appendage may be critical in making the trunk a superb limb for foraging

Regarding perceptual limitations on behavior, Lea, et al. (2006) discuss the “logic of the stimulus.” The authors theorize that the common behavioral learning paradigm leaves out the taxon specific perceptual biases of the particular organism. Each species’ particular perceptually modeled cognitive logic affects the organism’s response to stimuli in different ways. They propose that rather than thinking in terms of s-r (stimulus-response) , it should be reformulated as s-o-r (stimulus- organism- response) because the perceptual and cognitive facilities of the animal affect the response to the stimulus. This manner of thinking harkens back to von Uexküll’s (1957) concept of umwelt, the perceptual and experiential world of each organism. The elephant’s umwelt affects its response to the stimulus of the food.

To test this hypothesis, I devised a new set of experiments in which the elephants were given a second type of tool to use that would potentially enable them to reach food placed overhead but beyond their truck reach. Rather than a tool held in the trunk, I provided the elephants with a platform which they could move into position and stand on to reach food placed overhead. They would also be provided with the affordance of sticks and thus a choice in potential tools.

A second reason that the elephants might not have used the sticks in the experimental sessions may be due to previous keeper interventions. Over the years, the elephants may have been warned not to thrust items through the bars towards the public and are now reluctant to do so. In order to negate this possibility, the following experiments were moved outside the elephant house into the elephants' yard. Food was hung overhead so that the elephants were no longer reaching through the bars outside of their space to reach the food.

A third possible explanation for the elephants' inability to solve the problems is that the elephants are not capable of solving "insight-like" problems. In order to test this possibility, an "insight" problem that did not use tools was given in the elephant house in Experiment 4.

Chapter 4: Experiment 4: The Chain Problem

Given the results of the problem solving tasks in Experiments 2 and 3, I decided that it was necessary to determine if the elephants were capable of solving a problem through the bars of their stalls without using sticks. I also wanted to present the elephants with a problem solving paradigm that would allow the investigation of their procedural approaches to solving the problem. Would they show trial and error learning or behavior more consistent with insightful problem solving? To investigate this, I used a paradigm devised by Köhler (1925) to study problem solving in chimpanzees and to specifically isolate insightful problem solving. The problem consisted of tying a strong string to an immovable rock outside of a chimpanzee's cage with a banana tied to the middle of the string. The string was placed on the ground at an angle to the cage with the free end placed between the bars (Figure 9). To attain the food the chimpanzee could not pull the string directly as that act did not move the food any closer because the bars of the cage blocked the string. The solution of the problem was to pass the string from hand to hand toward the rock until the string was perpendicular to the bars, bringing the food within reach. Four of the chimpanzees solved the problem after pulling on the string. One, who had not noticed the string, first vainly attempted to get the food using rocks or sticks, before devising the solution. After observing the situation, one chimpanzee solved the problem immediately. Köhler theorized that the solution to this problem represented insight because the animal has only two choices, pulling on the string or the solution of passing the string hand to hand. The chimpanzees that first pulled the string, transitioned rapidly to the solution. Köhler (1925) stated that even humans would first pull the string to see how strongly it was attached.

Beck (1967) used this same task to test insightful problem solving in gibbons. These lesser apes had previously shown inferior problem solving skills to the great apes. Using this task along with other string pulling tasks, Beck showed problem solving abilities in gibbons that were equivalent to the chimpanzee. He hypothesized that the previous inadequacies in gibbon problem solving performance resulted from the physical structure of the gibbon hand. As tree dwelling apes, their hands are more suited to holding branches and vines than objects such as cups or other objects lying on a flat surface. However, the anatomy of their hand makes them ideally suited for pulling strings, which allowed them to show insightful problem solving ability in this task.

This task is similar to the string pulling task used to test insight in birds (Heinrich, 1995). The birds have to pull a string with food tied on the end hanging from a perch. Like the chimpanzee string problem, this task involves multiple steps. The bird pulls the string with its beak and then stands on it to grab the string lower down, again using its beak. The birds repeat this motion until the food is within reach. Any error moves the food further away. The birds complete this task spontaneously, moving from one step to another to obtain the food without trial and error. Nissani (2004) attempted to replicate this task for elephants by attaching a rope horizontally to an elastic cord. Food was tied to the rope out of reach of the elephant. To get the food, the elephant like the birds had to pull the rope and stand on it, or the rope with the food on it would snap back. The elephants had to repeat this order of behaviors to obtain the food. Nissani’s test didn’t show insight in the elephants as they solved the problem through trial and error and failed to retain the solution in further testing.

The elephant house at the National Zoo with its barred stalls provided an ideal venue to attempt Köhler’s test on elephants. For the purposes of this research, this test would be able to show if the elephants are capable of problem solving in this situation. This experiment seeks to

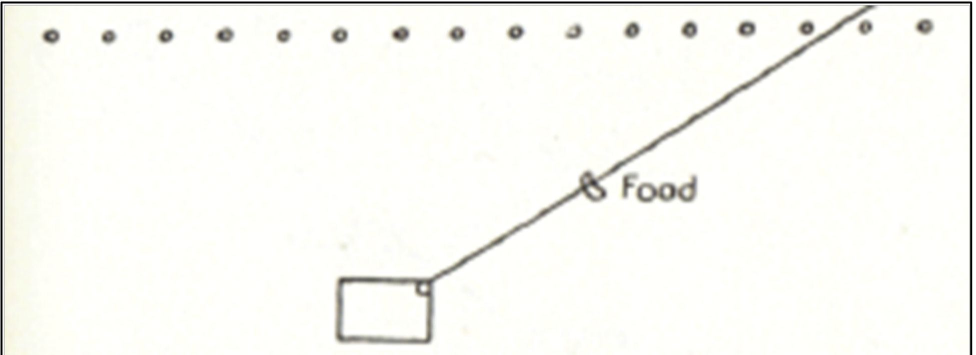

FIG. 14.

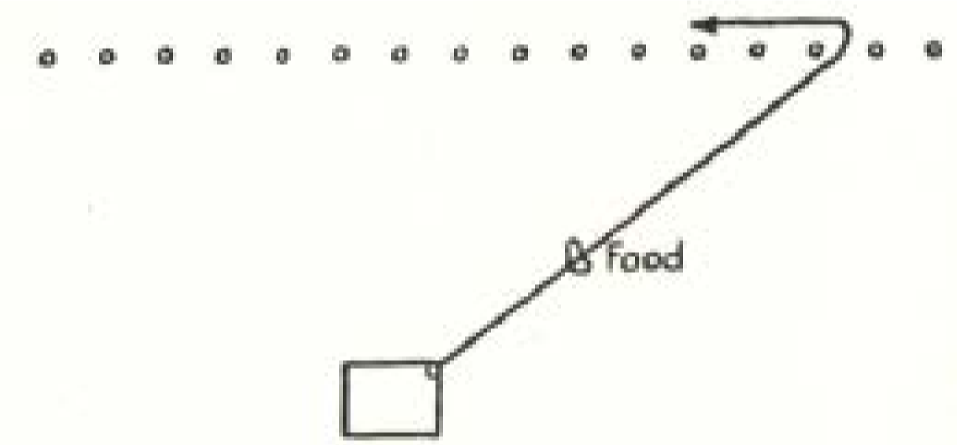

FIG. 15.

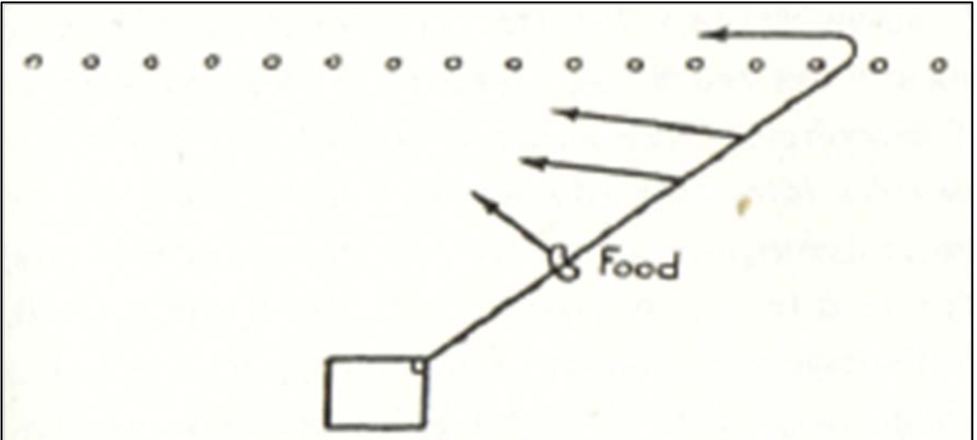

FIG. 16.

Figure 9. Köhler’s diagrams of his chimpanzee string problem (Köhler, 1925, pp. 308-310).

demonstrate if the elephants are capable of problem solving even though they had failed to solve problems using sticks.

Subjects

The same three elephants in Experiment 3, Ambika, Shanthi, Kandula, were the subjects of this experiment.

Materials and Methods

Facility. Same as in the previous experiments.

Apparatus. A 5.7 m chain was anchored at one end to the railing opposite the bars from the elephants' stall. The chain was positioned on the floor outside the bars of the elephant's stall attached to the railing at a distance of 2.7 m from the bars of the stall. A piece of melon, either honeydew or cantaloupe, was attached to the chain with a piece if twine and positioned ~1.5 m from the anchored end of the chain. The chain was bent at a right angle 1m from the free end. The chain was placed at an angle so that the elephant could reach the free end through the bars. Pulling on it from that position did not move the fruit within reach as the bars blocked the chain (Figures 10a and 10b).

Procedure. All the elephants were tested individually. All sessions were videotaped. Sessions began when the elephant entered the stall. Experimental sessions lasted 20 minutes. Trials were determined by completion of the task, i.e. pulling the fruit on the chain within reach and removing the fruit from the chain to eat it. All experimenters were placed out of view, either outside of the subject's sightlines or behind curtained blinds so as to avoid inadvertent cuing.

To reach the food, the elephant needed to pull and release the chain and reposition itself further down the bars to the newly reachable part of the chain, repeating this pattern a minimum of three times in order to obtain the fruit.

Results

All subjects successfully completed the task. Kandula solved the problem during his second session, completing the task once. In his third session, he completed the task 3 times. In his 4th session, he completed it once. In his fifth and sixth sessions, 8 times and 10 times, respectively.

Ambika solved the problem in her fourth session, completing the task twice. In her fifth, sixth, and seventh sessions, she completed the task 2, 6 and 9 times, respectively.

Shanthi solved the problem in her third session, completing the task 10 times. In her next session she completed the task 9 times. Kandula and Ambika both manipulated the chain multiple times, moving, pulling, and shaking it. Shanthi never touched the chain until her third session when she completed the task in 1 min 16 s.

Figure 11 shows the number of times each elephant “touched,” came into contact with the chain in any way, prior to solving the problem. Figure 12 shows the duration of each successful trial. Figure 13 shows the number of pulls on the chain it took for each elephant to obtain the melon in each successful trial.

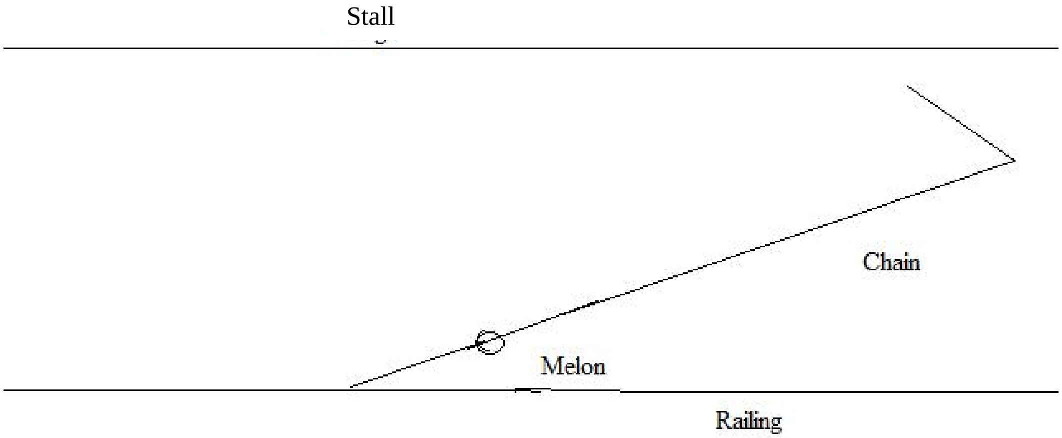

Figure 10a. Positioning of chain for Experiment 4.

Figure 10b. Photo of experimental setup for Experiment 4.

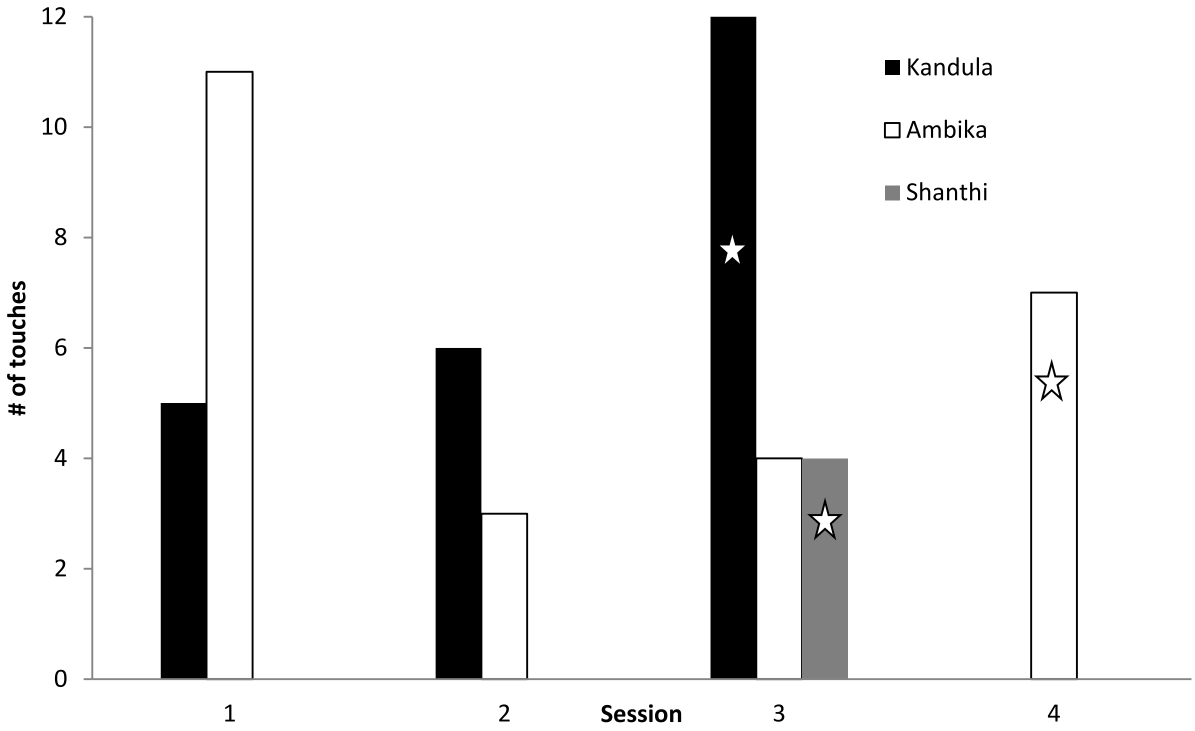

Figure 11. Number of times each elephant touched the chain until the first successful trial. Successful trials are indicated by columns marked with stars.

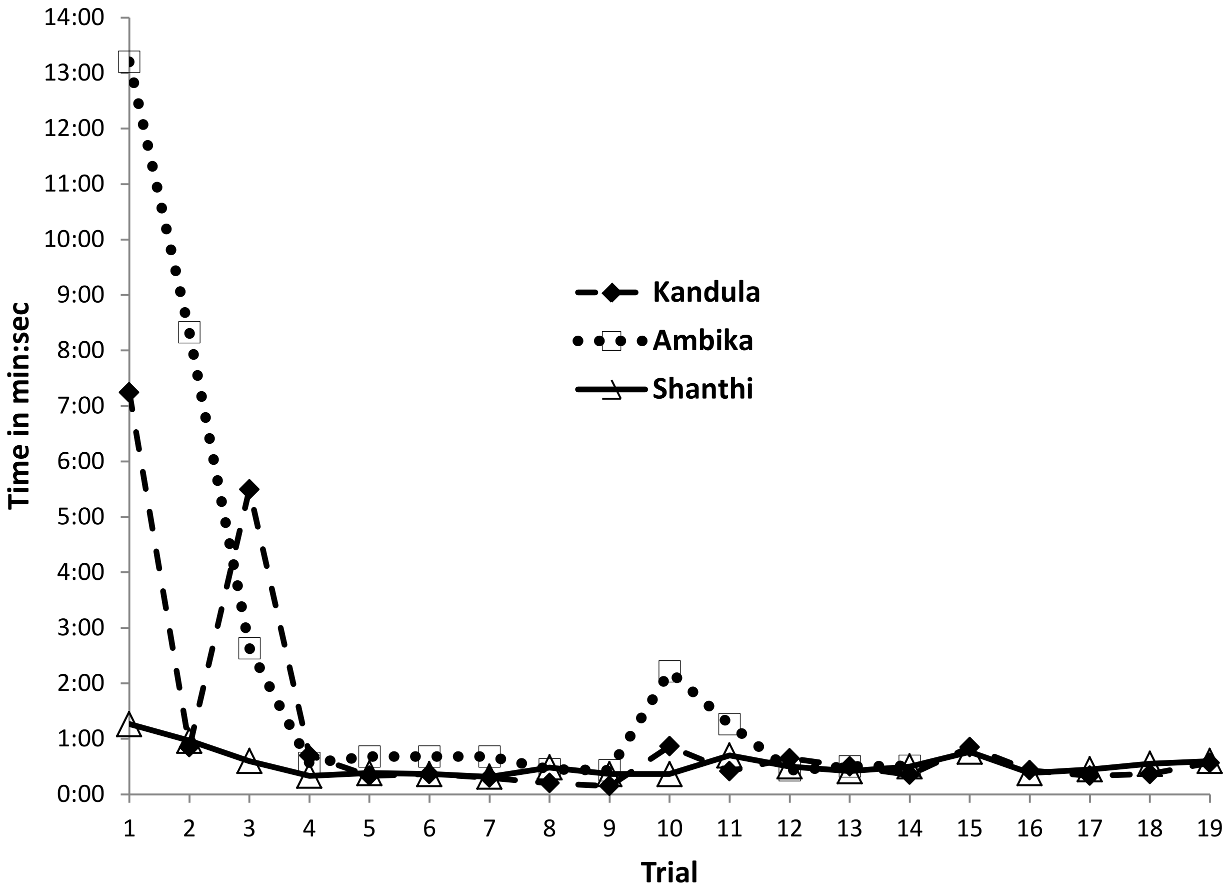

Figure 12. Duration of each successful trial for each elephant in minutes and seconds.

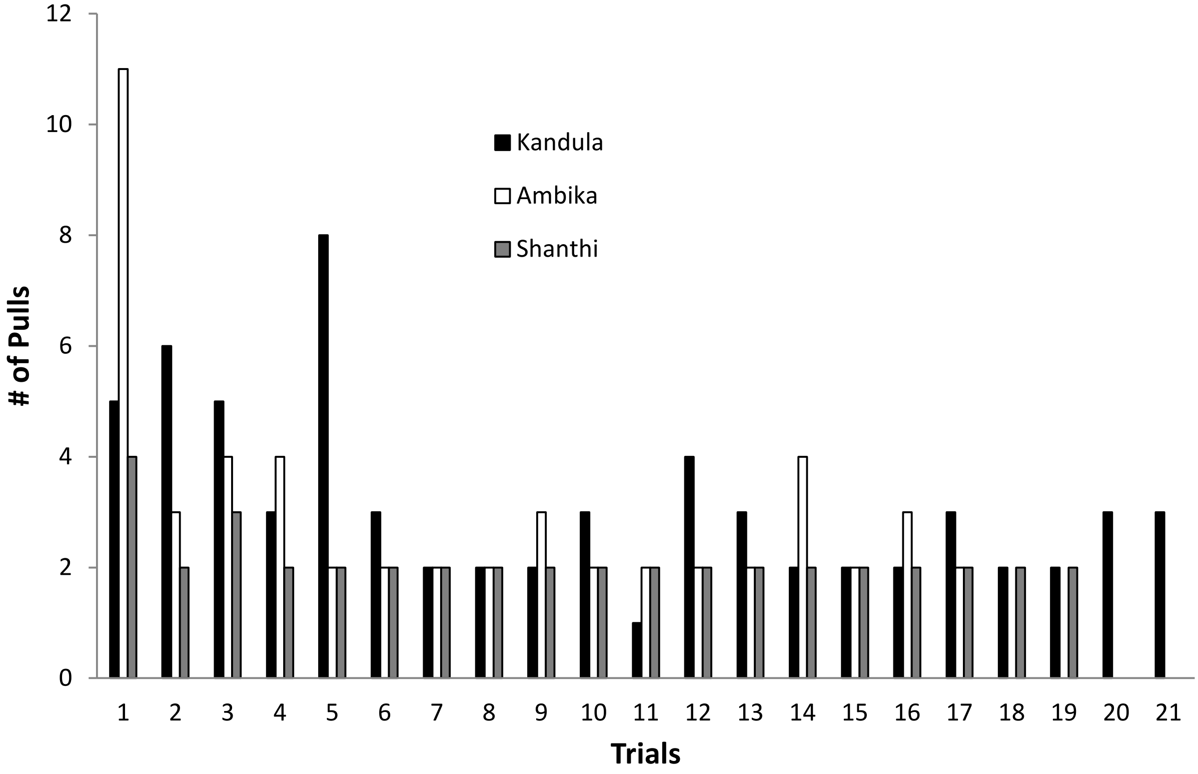

Figure 13. Number of pulls on the chain to prior to the successful completion of task for each elephant.

Discussion

All three elephants solved the chain problem. Kandula and Ambika solved the task through trial and error, pulling and shaking the chain numerous times over two to three sessions before arriving at the solution. Although Köhler may have considered the abrupt transition between pulling on the chain and arriving at the solution insight in the chimpanzees, I do not think it is possible to make the same assumption for these two elephants. They manipulated the chain in multiple ways, pulling and shaking it, and their first successful completion of the task was not smooth or rapid: 8 min 20 s for Ambika, and 7 min 15 s for Kandula. Once they had solved the problem, their performance grew progressively faster and more efficient (Figure 12).

Shanthi, however, solved the problem differently. She showed behavior that appeared to be consistent with Thorpe's (1963) definition of insightful problem solving. She never touched the chain prior to her first successful completion of the task and appeared to observe the chain and the fruit during two sessions. When she solved the problem, her performance was rapid and in the following trials she proceeded to complete the task progressively faster and with greater efficiency. All three elephants demonstrated another solution to the problem. Towards the end of the experiment the elephants learned that they could obtain the fruit by shaking the chain until the melon bounced off, sometimes in their direction. This experiment shows that the elephants are capable of solving a problem through the bars of their stall and without the use of a stick.

All the elephants had prior experience with chains. They are common in and around their enclosures. Their enrichment items are suspended from chains. It is not unusual for the elephants to pull on chains. However, the setup of the chain problem, anchored at one end, lying on the floor at an angle to the bars of the stall, is unusual and unlikely to have been encountered before. Although Shanthi was accustomed to pulling chains, the exact sequence of actions performed, pulling the chain, dropping the chain, moving to the next opening between bars and repeating the same actions until the fruit was within reach, were far more complex.

Althought it may be argued that Shanthi's spontaneous and rapid performance indicates an insightful solution to this problem, without her complete life history it is not possible to know to an absolute certainty that Shanthi had not encountered this problem in the past. Furthermore, her step-by-step performance on the task could also indicate a case of rapid learning rather than an insightful solution to the problem. Until further research is conducted on a subject with a more complete history, I cannot state that, in this case, there is irrefutable evidence for insight.

Chapter 5: Insightful Problem Solving though Tool use in an Asian Elephant

(This research has been published in the journal PLoS ONE
(Foerder, Galloway, Barthel, Moore III, & Reiss, 2011).)

Elephants have large complex brains (Shoshani, Kupsky, & Marchant, 2006), possess an elaborate social structure (Poole & Moss, 2008a) and are generally thought to be highly intelligent (Byrne, et al., 2009). Compared to the vast amount of cognitive research in other species, such as primates and birds, a full accounting of the elephant's cognitive abilities is far from complete (Plotnik, de Waal, Moore, & Reiss, 2009).

Surprisingly, given the extent of elephants' cognitive abilities as we know them, the few cognitive studies conducted in problem solving maintain that elephants perform poorly in spontaneous or insightful problem solving tasks (Hart, et al., 2008; Nissani, 2004). This cognitive deficit is unexpected because spontaneous problem solving has been shown in various species (Beck, 1973; Bird & Emery, 2009a; Köhler, 1925; Werdenich & Huber, 2006)with similar cognitive abilities. In Köhler's (1925) classic studies, for example, chimpanzees solved problems suddenly, without trial and error, by using sticks, boards, and even a person (on which they climbed) to acquire bananas hung overhead beyond their reach. Köhler claimed this was indicative of insight.

In perhaps Köhler's most famous experiment, one chimpanzee, Sultan, stacked boxes to obtain fruit hanging overhead. After moving one box in an attempt to acquire the fruit, Sultan found that he could not reach the fruit. Köhler described that Sultan then picked up a second box, not to stack it on the other one, but in apparent frustration, to swing it around and possibly throw it at something. Suddenly, Sultan stopped and in a rapid change of temperament took the box and placed it on top of the first box. He then climbed the stack to obtain the fruit. It is this sudden shift in the animal's behavior that Köhler identifies as insight (Köhler, 1925).

In Experiments 2 and 3 of this research, the elephants showed that they were capable of using sticks in tool-like ways. They hit the walls, floors, and hanging enrichment items, pryed the doors, and threw the sticks. However, the elephants did not use the sticks to obtain food placed outside the bars of their stall. They neither used the sticks to pull a food tray closer nor knocked the fruit out of a tree. Experiment 4 provided evidence that the elephants were capable of solving a problem through the bars of their stall that did not require the use of sticks. Kandula and Ambika solved the chain problem through trial and error, but Shanthi exhibited an insightful solution. It was thought that the bars may be impeding the use of sticks, possibly because the elephants had been reprimanded previously for pushing sticks through the bars. To remove this obstacle, all subsequent studies were conducted in the outside yard, adjacent to the elephant house.

The question arose as to whether the elephants' failures were less a consequence of their lack of problem solving ability, but rather that the bars were impeding the elephants' performance or that the tasks were not ecologically valid. To account for these possibilities, we conducted a second series of tests in the elephants' outdoor yard. See Table S1 for an overview of the experiments. A bamboo branch baited with fruit was hung out of trunk-reach, loosely suspended from an overhead cable. The cable stretched between the roof of the elephant house and a tree in the elephant's yard. The branches' position varied along the length of the cable for each trial. We provided the elephants with sticks and a large movable object that could be used as a tool on which to stand to reach the baited branch. The male elephant, Kandula, was provided with a large, movable plastic cube with which he had previous experience as an enrichment object. The females were provided with an aluminum tub on which they and Kandula had been trained to stand for husbandry examinations. Both objects could accommodate and support the elephants' front two feet. (See Figure 1*A* for experimental setup.) The females had prior training in pushing large objects (Table 1). Kandula did not receive this training but had previously been seen pushing objects. However, the elephants were neither trained to move objects in order to stand on them nor to use this behavioral sequence to obtain food or other items. Neither the 7-year-old male nor the 61-year-old female had ever been observed moving objects to stand on to obtain food. The 33-year-old female had been observed moving and standing on objects to reach items several times in her adolescence, but not since then, nor since the birth of her son, Kandula.

As in the prior experiments the elephants were provided with sticks. They were also provided with objects that could be moved and used as platforms on which to stand to reach food hung overhead and out-of-reach in the outside elephant yard. The females had prior training in pushing large objects (Table 1). Kandula did not receive this training but had previously been observed pushing objects. However, the elephants were neither trained to move objects in order to stand on them nor to use this behavioral sequence to obtain food or other items. Neither Kandula nor Ambika had ever been observed moving objects to stand on to obtain food. Shanthi had been observed moving and standing on objects to reach items several times in her adolescence, but not since then, nor since the birth of her son, Kandula.

Four experiments were conducted to test if the elephants would move an object for use as a platform to obtain the fruit and branch placed out-of-reach or a use stick to knock them down. If they did use the object, could they generalize this use to different placements and objects? Finally, I tested if the elephants would stack multiple objects in an attempt to reach the food. See Table 2 for an overview of Experiments 5-8.

Table 2

Overview of Experiments

Experiment	Protocol	Elephant	# of Sessions/ Period of Days
5	Tool use with cube	K	9/12
5	Tool use with tub	S	16/ 19
5	Tool use with tub	A	16/19
5	Tool use with tub	S & A	12/17
6	Cube displacement	K	5/14
7	Tire as tool	K	4/5
8	Block stacking	K	9/9

Experiment 5: Tool Use

Subject

The same three elephants in Experiment 3, Ambika, Shanthi, Kandula, were the subjects of this experiment.

Materials and Methods

Apparatus. A 7.62 m cable was run from the roof of the elephant house to a tree in the yard. The height of the cable was 6.25 m above the ground at its center. A movable shuttle attached to a rope pulley was positioned on the cable. Lengths of leafy bamboo with fruit attached at the bottom were hung from the shuttle by a trimmed branch so that they could be pulled or knocked off. Fruit was attached to the bamboo by impaling it on branches with leaves. Fruit is a preferred food and each length of bamboo had three pieces of fruit that was varied among melons (cantaloupe or honeydew), apples, bananas, and oranges.

Four 1.8m lengths of bamboo sticks were placed in the yard, two leaning against the tree and two placed on the ground beneath the food. In addition, Ambika and Shanthi were given an elephant “tub,” a round aluminum stand 0.61 m tall and 0.75 m in diameter. Kandula was given a 0.61 m plastic cube that supported his weight (Figure 14). Both the tub and the cube could accommodate the front two feet of the elephant. Neither of these items were novel. Ambika and Shanthi had been previously trained to stand on the tub (see Table 1.). Kandula had previous experience with the cube as an enrichment item. Different items were used because 1) the cube might not support the weight of the larger elephants and 2) Kandula, being more playful, might pick up the metal tub and throw it, creating dangerous containment issues. The platforms were placed approximately 3.66 m from the food placement. Exact distance and position varied.

Figure 14. Elephants in Experimental Conditions. (A) An overhead view of the positioning of the elephant tub, sticks and suspended baited branch, with one of the adult female elephants. (B) The juvenile male, Kandula, standing on the cube and reaching for the branch baited with food.

Procedure

Sessions were set at 20 minutes in duration. Later sessions, with the two females together, were 30 minutes in duration. If food and sticks were still available, sessions were sometimes extended because of other responsibilities of the keeping staff. Overall, sessions with individual elephants averaged 26 minutes. Trials were determined by completion of the task. Experimenters were positioned on the roof for both observation of the experiment and placement of the bamboo. The first two sessions were used to acclimate each elephant to feeding from the overhead bamboo stalk and determine the proper height to put the food out of reach. No sticks or other objects were in the yard during these sessions.

Each session began with the elephant receiving one length of bamboo with fruit that it could reach with their trunk. The bamboo was pulled into position approximately halfway along the cable using the pulley. The position of the food was varied. After the elephant took the first bamboo branch, it was replaced by a length of bamboo that was out of trunk-reach unless the subject stood on a platform. If this branch was taken, or needed replacement, it was replaced with another similar piece until the end of the session. After 16 sessions, it was decided that if the two females were tested in the yard together, the session could be extended from 20 to 30 minutes. Twelve subsequent sessions were conducted in this manner.

Each elephant was tested individually for approximately 20 min sessions. The elephants were first acclimated to new experimental conditions by giving them easily obtainable (within trunk-reach) baited branches on the cable. I ran 28 sessions with the female elephants and 8 sessions with the male.

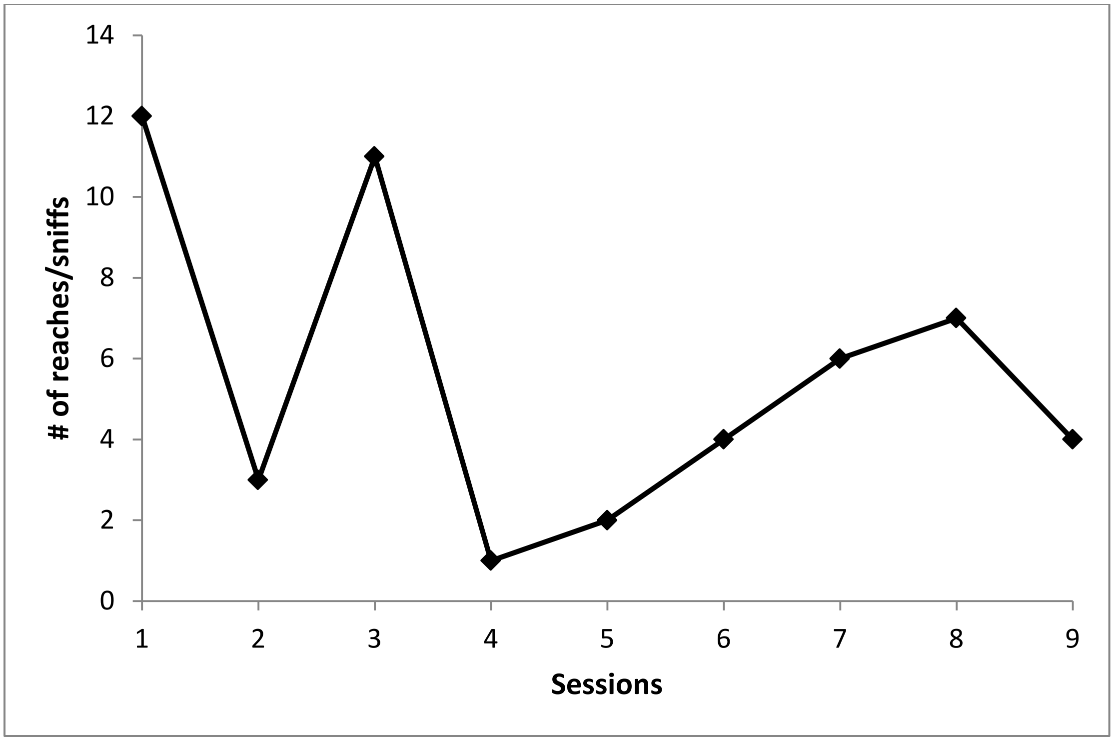

*Figure 15***.** Graph of Kandula's interest in food. Amount of times elephant either sniffed at or reached for food without acquisition in each session. Kandula acquired food with tool in sessions 7, 8, and 9.

Results

During all sessions, the females showed interest in the food by reaching for it but never attempted to use the sticks or move the tub to obtain it. I discontinued further testing with them.

Kandula also showed interest in obtaining unreachable branches as evidenced by sniffing and trunk-reaching behavior in all sessions (Figure 15) but failed to use sticks as tools to obtain the food. He moved the cube in two of the first six sessions (sessions 1 & 4), but never towards the food. In the first session, Kandula stood on the cube once briefly after rolling it away from the suspended food to an adjacent wall. At no time did he reach for any items while on the cube.

In session 7, Kandula had difficulty removing the first reachable branch from the cable. Four minutes into the session, he obtained the fruit but was unable to pull down the entire branch. He left the food location and returned to the area one minute later, rolled the cube from its original placement to the suspended food's location, stood on it with his front two feet and obtained the branch with his trunk (Figure 14b). Even though he sniffed and reached for the replaced food, he did not use the cube again to acquire food during that session.

The next day, in session 8, approximately two minutes after the placement of the first unreachable branch, Kandula rolled the cube to the food area, stood on it, and obtained the food in the same manner as in the previous session. In addition to using the cube for food acquisition, he also moved the cube and stood on it to explore the interior of an enrichment object affixed to a tree near the food site and, at the session's end, rolled the cube to the yard's periphery and stood on it to reach for blossoms on an overhanging tree branch. During this session, he used the cube as a tool to obtain food or other objects a total of 9 times, rolling the cube from 2-10 turns in each effort. Beginning in session 9 all food was hung out of reach in all trials. Kandula used the cube in the same manner to obtain food in subsequent sessions. The location on the cable of the baited branches was changed for each trial in the sessions. Kandula readjusted the position of the cube accordingly (Figure 16).

Experiment 6: Tool Displacement

Subject

Kandula.

Materials and Methods

Apparatus. Same as in Experiment 5.

Procedure. Both sticks and the cube were available. At the beginning of each session the cube was placed in a different position (Figure 16). All positions described from experimenter's vantage point on roof.

Session 1: Placed 10.4 m to left of food.

Session 2: Placed approximately 21.3 m away from food by pool.

Session 3: Placed 3.1 m away on opposite side of fence.

Session 4: Placed 17.4 m away in "bull gate". Cube was not visible upon entry from elephant house.

Session 5: Placed in same position as in session 4.

Results

I conducted 5 sessions in experiment 5 to test whether Kandula would search for and retrieve the cube when it was placed in different areas of the yard. In the first 3 sessions, the cube was placed at different distances from the food. In each case Kandula searched for and retrieved the cube and then used it to obtain the food. In the last 2 of these 5 sessions, the cube was hidden inside a walled passageway, a position invisible to Kandula upon entry. In the first of these sessions Kandula found the cube and used it to obtain the food. To test if Kandula could recall a previous placement, the next day the cube was again placed in the same hidden location as the previous day. Kandula went directly to the passageway and used the cube in the same manner.

Distances and times to initial discovery of the cube are shown in Figures 16 and 17.

*Figure 16***.** Photo of elephant yard with positions and distances of block placement. The yard is 25.91 m wide x 24.38 m deep. The arrow marked with a star indicates the food placement. Session indicated by numbers in arrows. Elephant entered from elephant house door at center bottom of photo.

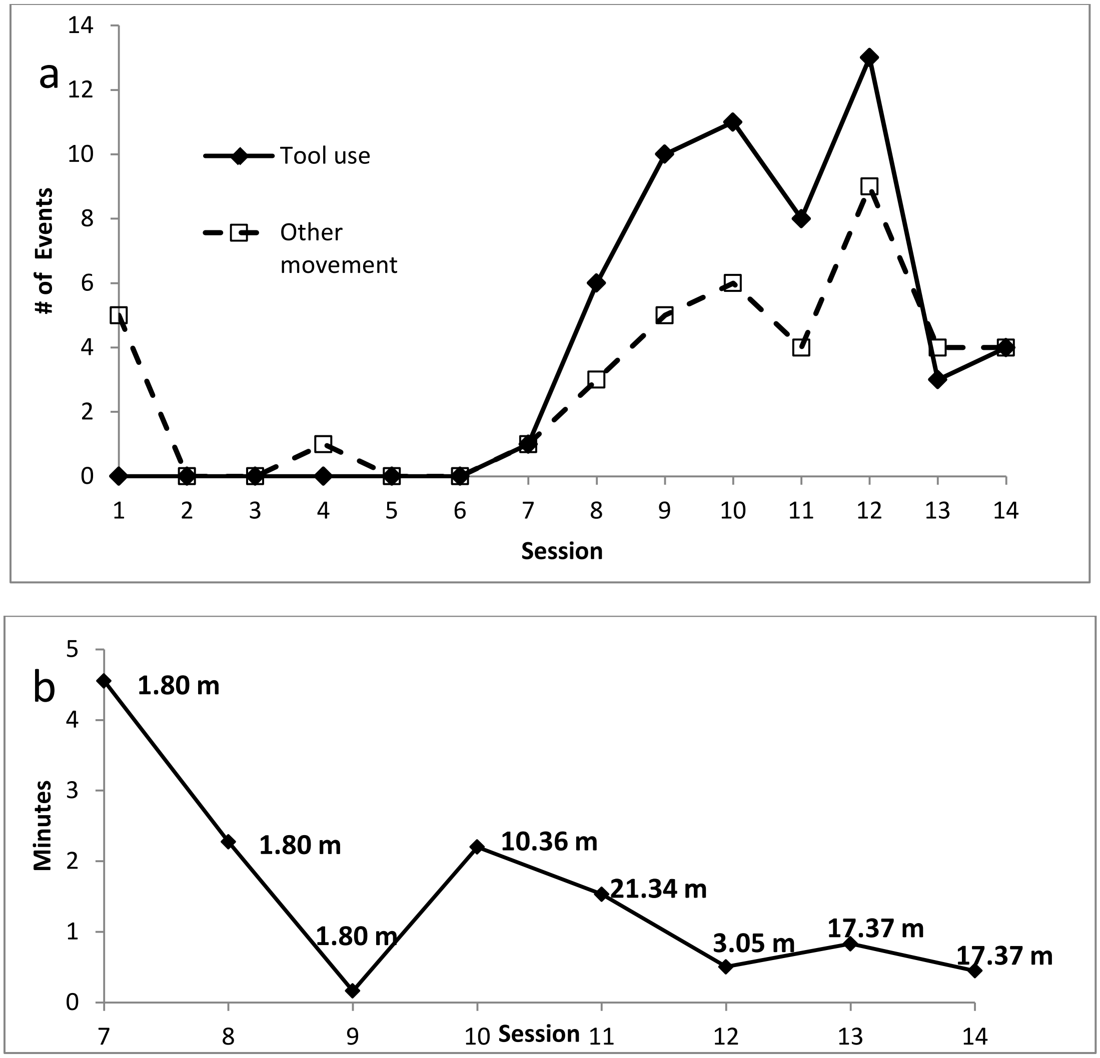

Figure 17. Kandula's use of the cube as a tool. (a) The number of times Kandula rolled the cube in each session that culminated in its use as a tool (i.e., moving the cube, standing on it and reaching for an object) or other movement (e.g., random movement of cube without standing on it) across trials. (b) Latency to the initial rolling of the cube for use as a tool to acquire food in each session. Distances of the initial placement of the cube from food are marked in meters (m). In session 12, the cube was placed on the opposite side of a fence which the elephant could walk around. In sessions 13 and 14, the cube was placed within the entryway to the adjacent yard, a position not visible upon entry from the elephant house.

Experiment 7: Tool Generalization

Subject

Kandula

Materials and Methods

Apparatus

Food presentation same as in Experiment 5. The cube was replaced by a large tractor tire, 1.27 m in diameter, 0.53 m thick.

Procedure

Same as in previous experiment. Four sessions were conducted. In each session, the tire was placed in a different position in the yard.

Results

In experiment 7, Kandula showed the ability to transfer his tool use to a different object. In three of the four sessions Kandula used the tire as a tool, rolling it to the suspended branches and then standing on it to obtain the food. He used it twice in sessions 1 and 4, and once in session 2.

Experiment 8: Stacking

Subject

Kandula

Materials and Methods

Apparatus. Food presentation same as in Experiment 5. The cube was replaced by three wooden butcher block cutting boards, 0.61m x 0.46m x 5.7 cm. The butcher blocks were the only novel objects that were used in the study. In addition to the boards, four other items previously used for enrichment were provided. In the first session, a blue plastic disc, 5.0 cm x 0.60 m, a green plastic cone, 0.61m, a hollow plastic ball, 0.46 m, and a hard plastic ball, 0.76 m.

After the first session, the hard plastic ball and the hollow plastic ball were replaced with a 0.61 m round flat blue barrel lid. Bamboo sticks were provided as in previous experiments.

Procedure. ***Pre-session.*** There was some doubt if Kandula could handle or move the flatter butcher blocks. Therefore one session was conducted in which Kandula was just exposed to a single butcher block in the yard without food or other objects or the experimental set-up. He showed facility in moving and carrying the block. Subsequent sessions were run without altering the blocks.

Nine sessions were conducted. In the first session, the butcher blocks were interspersed with the enrichment items, in a semicircular array, ~4.6 m from the food area, with ~1m separating the items. In subsequent sessions, the items were placed in a straight line parallel to the food area, with ~1m separating them. The midpoint of the line was ~4.6m from the food. The order of blocks and enrichment items was randomized. The baited branches were positioned so that it would be necessary for Kandula to stack three blocks to reach them.

Results

Kandula first touched several items and then moved two items, a plastic disk and a block, under the suspended branches, placing one front foot on each in an unsuccessful attempt to reach for branch. He solved the problem in an unexpected novel manner, moving and standing on the object closest in size to the absent cube, a large ball. He had not previously been observed standing on unstable platforms. He repeated this behavior 9 times during this session. During the session’s last minutes, Kandula picked up a block ~2 m from the food and placed it directly on top of a block that he placed under the food in a previous attempt. He stood on the stacked blocks and attempted to reach the food but was unsuccessful. He stacked two blocks again in the second and sixth sessions but each time his trunk was several inches from the food.

Discussion

These results provide experimental evidence that an elephant is capable of insightful problem solving through tool use. Evidence for this ability is indicated by the suddenness of Kandula's problem solving behavior without evidence of prior trial and error learning. His persistent use of this problem solving technique in subsequent sessions and his transference to other objects is consistent with the definition and other criteria that some have set for insightful problem solving (Nissani, 2004; Thorpe, 1963). Elephants in the field (Sukumar, 1997) and those in this study have been observed standing on stationary objects to attain items. However, Kandula's movement of the cube for use as a platform to attain otherwise unreachable food represents a novel and spontaneous solution to the problem. It could be argued that the elephant had prior training in a component of the novel problem solving task, standing on an object. However, the sequence of behavior exhibited by Kandula, moving the cube and standing on it to reach food, constitutes a more complex series of events that cannot be accounted for by past training. Kandula's use of the cube and other objects is also consistent with a current definition of tool use (Shumaker, et al., 2011) in that the object was moved and effectively oriented by the user prior to use to alter the position of the user itself. The onset of the elephant's stacking behavior may not be indicative of insight as it was preceded and followed by trials in which he persisted in trying to use single blocks. Kandula's behavior suggests, however, that he was actively trying to use different objects and strategies for food acquisition. Each time a method was unsuccessful, he switched strategies. Table 3 presents the sequential order of behavior that Kandula exhibited.

These results support the hypothesis that although the trunk is a highly manipulable appendage, in food foraging its function as a sensory organ may take precedence. The problem in previous studies has been in treating the elephant trunk as a grasping appendage analogous to a primate hand. The trunk is a superb appendage to locate, examine and acquire food and other objects as it provides the animal with the interaction of olfactory and tactile information. The elephant's eye has a fovea directed at the end of the trunk (Pettigrew, et al., 2010) further facilitating the sensory interaction with visual information. These deficits might not deter the elephant from using a trunk-held tool for other tasks but they may inhibit the use of such tools to acquire food. Although elephants have shown the greatest frequency and diversity of tool use of any non-primate mammal, they use tools primarily for skin care (Chevalier-Skolnikoff & Liska, 1993). In an extensive review of elephant tool use, only one example of an elephant using a trunk-held tool to acquire food was found (Chevalier-Skolnikoff & Liska, 1993; Zedtwitz, 1930). Kandula's placement of the cube to use as a platform brought his trunk closer to the food allowing him to take advantage of his trunk's sensory abilities. I posit that previous failures to observe insightful problem solving in elephants (Hart, et al., 2008) is not indicative of a lack of cognitive ability but rather is due to the reliance on problem solving tasks that precluded the use of the trunk as a sense organ. These experiments demonstrate that elephants are capable of insightful problem solving. When given the proper circumstances, elephants, like humans and several other species, can demonstrate "aha" moments.

Table 3

List of all behaviors that the elephant used to reach for food or other objects in the first block stacking session, Experiment 4, Session 1,and if they were successful in acquiring the food.

Time in Session	Reaching Behaviour	Successful
21 s	Rolls ball to food. Places foot on it but does not stand	No
2 min 42 s	Brings block next to disc (previously brought) and stands with one foot on each and reaches for food.	No
2 min 52 s	Rolls ball to food and stands on it.	Yes
3 min 9 s	Rolls ball to food and stands on it.	Yes
3 min 38 s	Rolls ball to food and stands on it.	Yes
4 min 8 s	Rolls ball to food and stands on it.	Yes
5 min 22 s	Rolls ball to food and stands on it.	No
7 min 28 s	Carries single block to food and stands on it.	No
13 min 20 s	Rolls ball to food and stands on it.	No
13 min 34 s	Rolls ball to tree and stands on it, reaches towards tree.	No
14 min 20 s	Carries single block to food and stands on it.	No
16 min 45 s	Gets off block and reaches with feet on ground.	No
23 min 43 s	Carries single block to block previously placed, stacks it on top and stands on it.	No
23 min 46 s	Kneels on back legs, placing head and trunk in a more vertical position with feet on stack.	No
24 min 24 s	Stands on stack	No
26 min 20 s	Rolls ball to food and stands on it.	Yes
27 min 11 s	Rolls ball to food and stands on it. Attempt aborted due to end of session.	N/A

Note. Times refer to time from beginning of session. At 5 m 22 s, the elephant had removed enough leaves from the branch so that it was no longer reachable. Branch was replaced at ~10 min.

Chapter 6: Experiment 9: Trunk held object use towards food vs. objects

In experiments 5-8, Kandula used the cube but not sticks to obtain the food. As mentioned in Chapter 2, Kandula had previously used trunk-held sticks to hit the walls of his enclosure and non-food items. Therefore, I hypothesized that Kandula may have not held the stick in his trunk and used it as a tool to acquire food because doing so interfered with his olfactory and tactile senses. If this hypothesis is correct, then perhaps Kandula would use the stick on a non-food item such as a suspended toy. A non-food item, might not engage his olfactory sense to the same extent. Previously Kandula had been observed hitting suspended enrichment toys in his indoor enclosure during the experiments conducted there. If Kandula treated a suspended object differently from suspended food in the same position, this behavior would support the hypothesis.

I conducted a series of sessions in the outdoor elephant yard to test this hypothesis. Suspended food was alternated with a suspended ball, and Kandula was provided with sticks to test his reactions to the different suspended items.

Subjects

Kandula.

Materials and Methods

Apparatus. Food delivery as previously described. Bamboo sticks were set as previously described. A 10” rubber ball with a handle, either red or blue/green, was hung from a chain at the same length as the unreachable length of bamboo. No objects that could be used as platforms were provided for this experiment.

Procedure. The first trial of each session began with a reachable length of bamboo that was baited with melon. After Kandula had eaten the fruit and bamboo, the branch was replaced either by an unreachable length of bamboo with fruit or an unreachable ball suspended overhead. The presentation order was alternated by session. Each session was 20 minutes long. One item was hung for 10 minutes and then replaced with the other item for 10 minutes.

Behavior was coded in two categories: non-directed stick use and directed stick use. Non-directed stick use was defined as any use of the stick not in relation to the suspended item. Directed stick use was defined as any use of the stick either in contact with or pointed at the suspended ball. Non-directed stick use consisted of hitting the ground, walls, fence, or trees, rubbing the stick in the ground, throwing the stick anywhere but at the suspended item, and scratching one self. Directed stick use consisted of hitting or shaking the stick at the suspended item.

Results

Twenty-five sessions were conducted. One session was dropped from the analysis because an alternate toy (a plastic cube) was used. At no time did Kandula attempt to get the fruit with the sticks. At no time did Kandula hit either suspended item. He did shake the stick in the direction of the items.

An analysis showed no significant statistical difference in behavior towards the ball or the branch based on the order of presentation, Fisher’s exact test, $p = .206$.

There were 341 non-directed uses of the stick, 8 object directed uses, and 4 branch directed uses. No significant statistical difference was found between directed stick use towards the ball or the branch, Wilcoxon signed-ranks test, $p = .299$.

Discussion

These results do not support the hypothesis that Kandula would treat suspended food differently from a suspended object with a trunk-held stick. There could be many reasons for these findings. The hanging ball might not have held sufficient interest for Kandula. This object may have been frightening to Kandula, and his use of the stick appears to take the form of a threat. Kandula, as seen in Experiment 1, tends to be neophobic. The novelty of the suspended item may have created a fearful situation although he did not avoid the area near the suspended items. It is also possible that the position of the item, hung overhead in the middle of a cable, was also disconcerting.

Because Kandula had previously been seen to use sticks held in his trunk to hit non-food items, his limited interaction with the suspended ball is unexpected. In the 18th session of this experiment, Kandula used a stick to beat and probe an enrichment item that was suspended overhead in the tree: a large, upside down red plastic pot hanging from a chain with a tire attached to its interior (Figure 14a). This toy was not out of trunk reach, and he played with it on a regular basis without sticks. In Experiment 5, Kandula had rolled the block over and stood on it to play with this same enrichment item. The employment of the stick to investigate the toy in this experiment added a further novel method of investigation. This example indicates that Kandula uses sticks on overhead objects even though neither he nor the other elephants used a stick to acquire food. This example is some evidence supporting the hypothesis.

Further research is necessary to obtain more decisive evidence that supports this hypothesis. I continue to consider potential experiments that would verify that interference with the olfactory and tactile senses prevents elephants from using sticks for food foraging. One possibility might be to give the elephants a tube, such as plastic pipe, in which they could insert their trunk and that would extend their reach but maintain an opening for their sense of smell. However, this method seems awkward and would interfere with the trunk’s tactile sense. Other options may be to alter the original experimental parameters. The size, shape, and the color of the object could be changed to determine if that would create more interest for the elephant. The height at which it is suspended could be lowered. Perhaps if the object were within reach, at the same height as the first reachable baited branch, it would make the objects more equivalent to the elephant. In that case it could be better determined if there is a difference in the elephant’s reaction to food as opposed to an object. Future research on this group of elephants and other elephant populations may determine new research paradigms.

Chapter 7: Experiment 10: Social Learning

Humans and many other species are social learners. In social learning, one animal learns a behavior by observing it modeled by another animal. This process may occur through different mechanisms: stimulus enhancement, in which the animal’s attention is drawn to an object by the actions of the other animal; goal emulation, the animal attempts to achieve the same outcome that it has observed though not necessarily using the same method; and true imitation, the animal exactly copies a novel behavior that it has witnessed with the intention of achieving the same goal (Zentall, 2011). Social learning allows an animal to use information gathered by experienced others, eliminating the need for trial and error learning in that situation (Galef & Laland, 2005). Considering social learning in human animals, Bandura observed:

> Learning would be exceedingly laborious, not to mention hazardous, if people had to rely solely on the effects of their own actions to inform them what to do. Fortunately, most human behavior is learned observationally through modeling: from observing others one forms an idea of how new behaviors are performed, and on later occasions this coded information serves as a guide for action (Bandura, 1977, p. 22).

Social learning has been studied across a broad range of species (Galef & Laland, 2005). In insects, damselflies learn about predation threat based on conspecific and heterospecific cues, and bees learn foraging options from information provided by other hive members (Leadbeater & Chittka, 2007). Fish exhibit social learning in anti-predator behavior, migration patterns, foraging, and mate choice (Brown & Laland, 2003). In avian species, songbirds learn their songs from others (Marler & Tamura, 1964). New Caledonian crows learn their tool use techniques during their relatively long development period with their parents (Holzhaider, Hunt, & Gray, 2010). Large-billed crows learned to open puzzle boxes through observation using emulation rather than imitation (Izawa & Watanabe, 2011). It has been shown that chicks of domestic chickens learn types of food to forage and foraging sites (Daisley, Rosa Salva, Regolin, &

Vallortigara, 2011). Among mammals, rats socially learn to make food choices (Galef & Laland, 2005) and banded mongooses have shown social learning in food foraging techniques (Müller & Cant, 2010). In primates, social learning has been seen in wild lemurs opening puzzle boxes (Kendal et al., 2010). Cracking nuts with rocks has been shown to be socially learned in capuchin monkeys (Ottoni & Izar, 2008) and chimpanzees (Boesch, Marchesi, Marchesi, Fruth, & Joulian, 1994).

There has been little formal experimental research done on social learning in elephants (Byrne & Bates, 2011). In one study captive African elephants were provided with food-filled puzzle boxes with multiple means of access (Greco & Caine, 2011) A dominant female learned how to extract food from six different puzzle feeders. Five subdominant females were given access to the puzzle feeders after observing the model. No correlation was found between the method the model employed and the method the observer employed to open the puzzle box. It was found, however, that elephants that observed the other elephant engaged with the box spent more time investigating it and solved the problem more quickly than elephants that had not witnessed the model.

Although there has been little experimental evidence for social learning in elephants, there have been indications from field studies that they learn from social information (Byrne & Bates, 2011). Elephants have a long developmental period in which provides opportunities for learning from mothers and close relatives. Females stay in the family group through adulthood and males stay with the family into adolescence, from 11-14 years of age. During this period, they have countless opportunities to observe and learn new behaviors. For example, young elephants are often seen taking food from their mother’s mouths. This behavior may aid in instructing the young in proper food selection. (Lee & Moss, 1999). A report on vocal imitation in elephants suggests social learning capabilities (Poole, et al., 2005). Female African elephants have been seen to fake oestrus behaviors. It is hypothesized that they engage in this behavior to instruct naïve females in the proper ways to engage in oestrus behavior and relate to male suitors (Bates et al., 2010).

To further investigate whether social learning might play a role in the transference of a problem-solving technique, I conducted another experiment in which elephants could observe another elephant performing a novel task. In the previous series of experiments, Kandula would reliably roll the cube to stand on it to get food whenever the food was place overhead, out-of-reach. Neither Shanthi nor Ambika had ever attempted to solve the problem nor had they been able to observe Kandula doing so. This situation provided an opportunity for an experiment in social learning. Would Shanthi learn the solution to the problem of getting the food from observing Kandula as a model? The following experiment was designed to test whether Shanthi would observe and learn the problem solving behavior from Kandula and then when Shanthi and Ambika were housed together, would Ambika learn the problem solving task from Shanthi.

Methods and Materials

Subjects. Ambika and Shanthi. Kandula acting as a model.

Apparatus. The food delivery was the same as in Experiment 5. Kandula was provided with the cube from Experiments 5-8. The two females were provided with the elephant tub, the cube, and the bamboo sticks as in the previous experiments.

Procedure. Sessions were divided into two phases. In the first part of the session, the yard was preset with the hanging baited branch and the block. Kandula was the model in each session with Shanthi as the designated observer. Ambika could not take part as an observer because she and Kandula are aggressive towards each other. Shanthi was held in a stationary position in the yard facing the area where Kandula would demonstrate obtaining the food by moving the cube and standing on it. As Kandula was handled using protected contact, a keeper could not be in the yard with him. To allow the keeper to hold Shanthi while she observed Kandula, a door to the elephant house was opened wide enough for a person to pass but not an elephant. Shanthi was held in place standing outside the door of the elephant house through commands given by a trainer standing inside the elephant house. While Shanthi was being held, Kandula entered the yard and modeled the food acquisition behavior of rolling the cube and standing on it to acquire the food. This first phase was of variable duration. Shanthi was held until Kandula performed his food acquisition behavior three times. Kandula then returned to the elephant house. During Session 2, due to a zoo scheduling problem, Shanthi watched from inside the elephant house through an open door. The rest of the procedure was the same as when Shanthi observed while standing outside.

The second part of the session began after the yard was reset with the suspended baited branch, the block, the tub and the sticks positioned as in previous experiments. Shanthi was released from her position and Ambika was also let into the yard. The 30 minute testing phase of the session started at this point in which the elephants were observed to determine if they replicated Kandula's problem solving behavior.

Results and Discussion

Eleven sessions were conducted. In all sessions, Shanthi was facing Kandula during the demonstration phase. Because Shanthi is Kandula's mother, she has a tendency to watch Kandula and was observed doing so during the demonstrations. Shanthi showed some interest in the food in most sessions, indicated by reaching for and sniffing at the suspended food. However this interest varied by session (Figure 18). One minute before the end of the first session, after watching Kandula demonstrate the behavior, Shanthi placed each of her front feet, one at a time, on the tub without putting her weight down and while her second foot was on the tub pointed her trunk towards the hanging food. This was the first time she had placed a foot on the tub in any of the experimental sessions. In the ninth session, Shanthi moved the tub slightly and tapped on it with her trunk. No other changes were seen from the previous tool use trials, and she made no attempts to move the tub to stand on to acquire the food. Shanthi spent the majority of each session standing and swaying. She has a stereotypical sway, and this is not unusual behavior. Ambika spent the majority of time dustbathing, throwing dirt on her back. The elephants would occasionally roam the yard, play with and eat the bamboo sticks, and interact with each other.

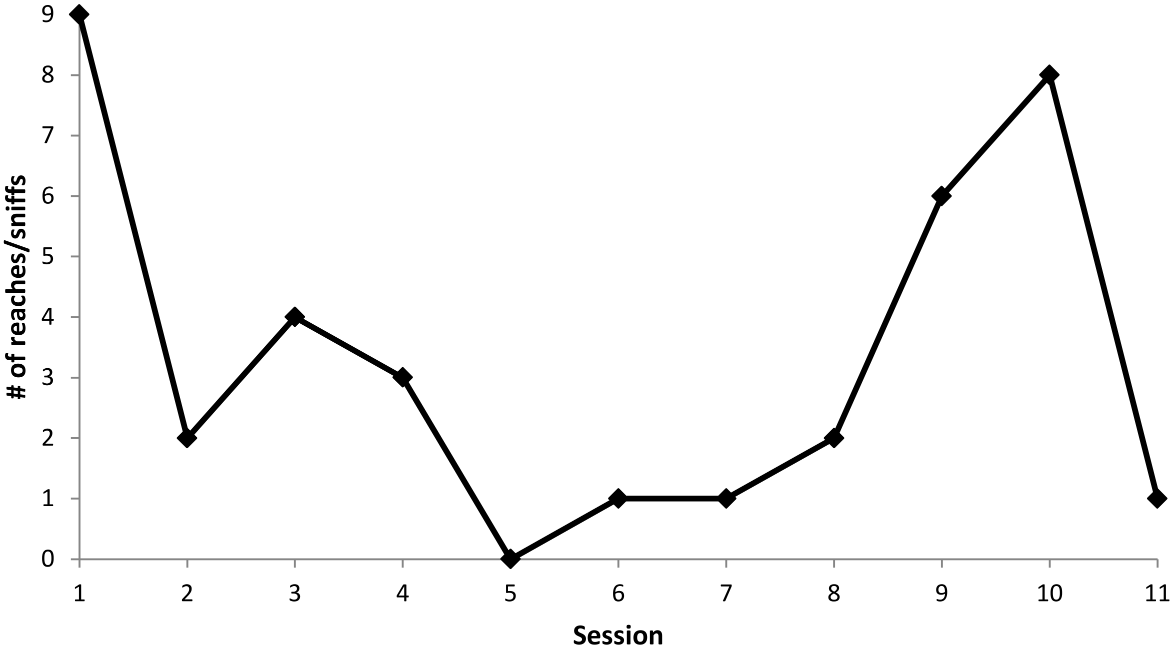

Figure 18. Shanthi's interest in food in Experiment 10 as shown by number of times the elephant sniffed or reached for the food for each elephant in each session.

There are several confounds and limitations in this experiment that should be considered. First, Kandula was using a different platform, the cube, than those platforms provided to the other two elephants who were given the tub. The cube, tub and sticks were all available in the yard to Shanthi and Ambika during the subsequent sessions and the elephants had the option of using the cube as a tool to acquire the food. Both Shanthi and Ambika investigated and moved the cube, but not in any manner that indicated that they would use it to obtain the food. At no time did either elephant use the sticks to attempt to acquire the food.

Another possible confound may be in the method that Shanthi was held in place. Since she was being held through commands from her trainer, her attention may have been split. It is possible that she was not concentrating on the model sufficiently to learn the behavior. A further confound may have been stress from the experimental session. A common behavior for Shanthi during these sessions was tapping with her trunk on the cube or tub. This behavior has been correlated with nervousness in this elephant by the elephant staff.

An interesting example of tool use did occur during these sessions. On five occasions, in sessions 2, 3, 5, 8, and 9, Ambika picked up the tub, turned in on its side, and placed it under the ventral side of her body. She then leaned on it for a period of time as it supported her weight. After a period of time, she would remove the tub from underneath her stomach and let it drop on the ground.

This experiment provides little support for the capability of social learning in elephants. Even though naturalistic observations imply that elephants are capable of social learning (Lee & Moss, 1999), several reasons could explain why the elephants might not exhibit social learning in this situation. Because the situation necessitated that Kandula be the model for Shanthi, it meant that the mother was in a situation which necessitated learning from the son, a dominant animal learning from a submissive. Nicol and Pope (1999) found that domestic hens' dominance status affected social learning. Submissive hens would only learn from more dominant ones. In a hierarchy such as that seen in elephant society, dominance may affect social learning, particularly in the case of a mother learning from a son.

Another possibility is that, while elephants may exhibit social learning, they may not learn visually or from a distance. Elephants are often in physical contact with each other for apparent reassurance and affection, play, and group defense (Poole & Granli, 2011). Similar to my hypothesis that they do not use sticks for food foraging because it interferes with their tactile and olfactory senses, perhaps elephants also need to engage these other senses for social learning. Empirical research to this point has not confirmed social learning in this species, and new experimental protocols may need to be devised to test the unique learning capabilities of elephants.

This task was very limited in scope so the results should be interpreted conservatively. The problems imposed by this particular experimental procedure may not have allowed the elephants to exhibit social learning. Other experiments should be conducted in which multiple elephants of different relationships can be exposed to a variety of tasks without human interference. Through further research, it may be possible to show empirical evidence for social learning in elephants.

Chapter 8: General Discussion

The results of the series of experiments conducted in this study provide compelling evidence that Asian elephants are capable of problem solving with tools. These results also provided the first evidence that elephants show behavior consistent with that defined as insightful problem solving. In Experiments 5-8, in problems with food hung out of trunk reach, Kandula showed a spontaneous solution to the problem and that he was capable of insightful problem solving using a tool, moving the cube to attain food that he was otherwise unable to reach. He was able to generalize this behavior to different positions of the box and food, and to another item, the tire. He has also shown that he is capable of constructing a tool by stacking two blocks to attempt to reach for food, but due to evidence of trial and error this solution did not appear to be insightful.

This series of experiments reveals that, in elephants, the unique quality of their manipulative appendage, the trunk, may influence the process by which they solve problems. The assumption that a given problem has a universal solution among different species is a faulty approach. Each animal is guided in their cognition by their own unique sensory/perceptual biases. In the case of the elephant, the trunk with which it manipulates items is also one of its prime sensory organs, its nose. The sensory interaction of olfaction, extreme tactile sensitivity (Rasmussen, 2006), and vision through the trunk-focused fovea in the eye (Pettigrew, et al., 2010) combine to make the trunk an extraordinary appendage, but one whose sensory capacities may occasionally take precedence over it manipulative ones.

The findings in Experiment 1 confirmed that the elephants are capable of means-end comprehension, but the results of Experiment 2 were surprising in that the elephants failed to use sticks as a tool to obtain the out-of-reach food tray. The elephants also did not attempt to use a stick to obtain the fruit from the tree in Experiment 3. The results of these experiments led to the hypothesis that a trunk-held stick may interfere with elephants' olfactory and tactile senses thereby prohibiting them from using a stick in food acquisition. To test this hypothesis, Experiment 9 was conducted in which Kandula was provided with sticks and either food or a ball suspended out of his trunk reach to ascertain if differential stick use would be seen with food or non-food items. However, this experiment did not provide evidence to support the hypothesis. No statistical difference was found in Kandula's stick use towards either item. These results, however, are not definitive due to a number of limitations, including the particulars of the size, shape, color, and placement of the object and Kandula's possible lack of interest interacting with it.

Although Experiment 9 did not confirm that elephants avoid using trunk held tools for food foraging, there is evidence from these studies that support the hypothesis that trunk-held tool use is governed by sensory/perceptual rather than cognitive limitations. The elephants used the sticks in many tool-like ways (see Appendix) but at no time did any of them attempt to acquire the fruit with a stick. While Kandula never hit the suspended ball, his use of the stick to hit a different item (the enrichment toy suspended from the tree) indicated that he treated a primarily visual stimulus differently from a food stimulus. When he was given an alternative tool (the cube) that was not held in his trunk while he was reaching for the food, Kandula was capable of solving a problem in an insightful way.

We can examine Kandula's problem solving behavior according to Nissani's (2004) criteria for insight. Kandula's solution showed no signs of being genetic (his mother did not exhibit the behavior), and it showed no signs of trial and error. Kandula's solution to the problem was a new behavior, not previously observed in this individual. He arrived at the solution suddenly and performed it smoothly. Kandula appears to have had a mental representation of the problem and solution as evidenced by retrieval of the cube from a previous unseen placement. The solution was retained and transferred across a variety of situations. As an example of Kandula's retention of the behavior, he has continued to use this behavior to reach items since the end of the research. The summer of the following year, a visitor at the National Zoo documented Kandula standing on a ball to reach a tree (chodencyo, 2010). Two years following the research, we replicated the experimental paradigm in new elephant facilities at the National Zoo to demonstrate Kandula's tool use for a television program (Suzuki, 2012). Upon entering the new elephant yard, Kandula approached and sniffed toward the out-of-reach baited branch, then immediately retrieved the cube, and moved it directly under the branch and reached the food. He also used the ball, and a novel item, a barrel as platforms to stand on. This provides further evidence that Kandula both remembered how to solve the problem and that he transferred the technique to the new facility.

While it could be argued that Kandula already had the behaviors he needed to chain to solve the problem because of his extensive training, his behavior does not appear to indicate that he used his training to reach these solutions. Although Kandula had been trained to stand on objects, he had already exhibited this natural behavior prior to training. He had not been trained to push things, but this is also a natural behavior that he had exhibited quite often in the past. Prior to this study, he had not been seen to move a platform to reach an item, as he did in this experiment (personal communication, M. Galloway, elephant manager, NZP). He also did not immediately produce the solution as chaining would indicate. He took seven sessions to arrive at his method to reach the food. When he did, he did so without hesitation, or trial and error. He was also able to extend this understanding to other placements and objects.

Shanthi’s performance in Experiment 4, the chain problem, was smooth, quick, and spontaneous. Although both Kandula and Ambika eventually solved the chain problem, their performances indicated trial and error behavior. As stated in Chapter 4, the chain problem was a unique task, and therefore Shanthi’s solution could not be generalized to other contexts. Although Shanthi's might appear insightful, it might be argued that the elephant’s prior experience with chains in similar situations could have influenced her ability to solve this problem. The postioning of the chain problem, anchored at one end, lying on the floor at an angle to the bars of the stall, would seem so unusual that it seems doubtful that the elephants had prior exposure to the problem. However, Shanthi's familiarity with the problem cannot be ruled out to an absolute certainty. The exact sequence of actions needed to be performed to acquire the fruit are complex: pulling the chain, dropping the chain, moving to the next opening between bars and repeating the same actions until the fruit was within reach. Shanthi performed this sequence spontaneously and rapidly. However, rather than this being a insightful solution it may be a case of rapid trial-and-error learning. Further research on other subjects needs to be conducted to affirm the insightful nature of this solution.

Although Shanthi's life history is not completely known, Kandula was born and raised at the National Zoo and has been observed throughout his life. He had never been seen moving an item to stand on to acquire an object. And yet, he was able to produce this pattern to solve this problem. He continued to use this behavior after the initial use. In the moment of insight, a new behavior pattern was added to this animal’s behavioral repertoire.

The Elephant Brain

Although this study provides evidence for insightful problem solving in elephants, previous research by Hart, Hart, and Pinter-Wollman (2008) previously concluded that elephants do not show insight. Their conclusions were based on their own unpublished study. They describe how they provided elephants with sticks to tip an overhead out-of-reach platform containing food. Hart, et al.(2008) also mention a similar unpublished study by Nissani with the same/similar results. Hart, et al.'s hypothesis for the lack of insightful problem solving implicated the structure of the elephant brain. The elephant's brain had been described as having neurons that are larger and less densely packed than the primate brain (Haug, 1987). Hart, et al. (2008) have speculated that elephant cortical neurons may have longer axons traversing more distant cortical regions and that this may result in decreased local compartmentalization resulting in increased time of information processing. Such slower processing has been posited as an explanation for the elephant's poor performance in cognitive tasks. They base their conclusions on estimations of neural density, structure, and brain organization as compared to the chimpanzee and human brain.

Although these calculations about the elephant brain seemed reasonable given available information, more recent studies of the elephant brain have revealed previously unknown differences. Jacobs, et al. (2011) have shown that the elephant's neural morphology is more complex than previously thought. The elephant has the largest brain of any land mammal (Cozzi, Spagnoli, & Bruno, 2001). At birth, the brain is only 35% of its adult size indicating the possibility of brain development through learning (Poole, 1996). The elephant brain is highly encephalized on the scale of a primate brain (Manger, Prowse, Haagensen, & Hemingway, 2012). The cerebral cortex "contains a rich variety of large neurons with expansive, spine-rich dendritic systems and, presumably, long axonal projections to interconnect these relatively sparsely packed neurons" (Jacobs, et al., 2011, p. 294). The elephant brain also does not exhibit the columnar organization of the primate brain (Bianchi et al., 2011). This current research on the elephant brain suggests possible greater integration of information, enabling advanced cognitive abilities (Jacobs, et al., 2011). Elephants are one of the few species, including human beings and cetaceans, which possess Von Economo neurons. Located in several brain structures, primarily the frontoinsular cortex and anterior cingulate cortex, these neurons are theorized to facilitate the processing of social information (Hakeem et al., 2009). Although the elephant brain has a different neuromorphology and organization than the primate brain, it appears to be capable of advanced cognition such as insightful problem solving.

The Insight Controversy

Since Köhler's challenge to Thorndike's learning theory (Köhler, 1925), the concept of insight has been controversial. The German word *Einsicht* does not necessarily mean insight. A note from Köhler's translator (Köhler, 1925) states that the word was translated as both intelligence and insight in the original manuscript. Perhaps if they had settled on the latter term the findings would not have generated as much controversy (Beck, 1980). Köhler's own definition was rather vague, intimating that we know what human insight is and the chimps appear to be using the same process (Köhler, 1925). Hartmann (1931) thought that the definition of the term insight was still vague and seemed to imply more about animal than human behavior. The implication of mentality on the part of animals went against Morgan's Canon (Morgan, 1894) that mental processes could not be implied in an animal unless all other explanations had been exhausted. Schiller (1957) theorized that insight could be explained by the use of innate motor patterns. Without presenting problems, he provided sticks and boxes to 52 chimpanzees and analyzed their play behavior. He concluded that all of the behaviors seen in insightful problem solving were present in the chimpanzees purposeless play behavior and that the chimpanzees were using innate behaviors that they exhibit in play to solve problems. For example, on giving the chimpanzees two sticks that connected by fitting inside each other, the chimpanzees performed this action in play, as well as threading the stick through a fence, even though there was no goal to be achieved. In a further analysis of both Köhler's and Schiller's research, Chance (1960) takes the middle ground. He finds that if the animal uses only previously seen invariable motor patterns then insight cannot be implied. However, if the chimpanzee is able to shift its behavior to a diversity of patterns in relation to the diversity of the aspects of the environment, then the chimpanzee can be said to have some comprehension of the problem. According to Thorpe's (1963) definition the "reorganisation of experience," new combinations of previously exhibited behavior patterns to solve a problem should be considered insight.

With the intention of showing that insight could be explained by a stimulus-response chain, Epstein, Kirshnit, Lanza, & Rubin (1984) used operant conditioning principals to train the constituent behaviors of an insight problem solution into a pigeon. They divided the action of moving a block and standing on it to peck at a plastic banana into two conditioned behaviors: pushing the block and standing on it to peck the banana. The pigeon showed what appeared to be insight-like behavior when faced with the problem: looking back and forth between the block and the banana until finally pushing the block over to the banana and standing on it to reach peck at it. The authors imply that the same process has happened in animals showing insight. The animals have learned previous behavior patterns and automatically chain the behaviors into the solution.

However, in a further study (Epstein, 1985), when the pigeon's behavior was broken down into three behaviors, pushing the block, standing on the block, and pecking the banana, the pigeon did not show the insight-like behavior. According to this second experiment, in an animal’s history it would have had to learn only the constituent parts of the problem and nothing else that might interfere with the solution. In a replication of the original pigeon experiment, Luciano (1991) showed that the behavior was controlled by the lack of reinforcement for the initial behavior. He also found that differences in training variations of the behavior, such as pushing the block away from a target interfered with “insightful” problem solving. In the case of the pigeon, the bird stopped pushing the block and shifted to the second behavior, standing on the block and pecking at the banana, because it did not receive reinforcement for pushing the block. In relation to Kandula’s cube rolling behavior, the elephant had previously used the cube as a toy, rolling it around for the apparent pleasure of it. When he rolled the cube to the food, whatever intrinsic reinforcement he received was still inherent in the action. There would have been no lack of reinforcement at this point in his solution forcing him to move on to the next behavior.

Spence (1938) investigated insight in chimpanzees solving discrimination problems. He hypothesized that the arrival of an insightful performance was predicated on the excitatory value of the two stimuli. This value was arrived at by the reinforcement history of the stimuli. If there was a large difference in excitatory values between the stimuli, learning the discrimination happened quickly if not spontaneously. If the two stimuli were close in value then the learning would appear to happen by trial and error. For Spence, insight in this situation could be explained the excitatory weight of the stimulus. However, Spence’s hypothesis may not address situations with novel stimuli or problems (Beck, 1980).

Although Beck (1980) was originally interested in insight in tool use problems, providing evidence for the ability in baboons (Beck, 1973) and gibbons (Beck, 1967), he later had second thoughts on the topic. Beck became more concerned with specifying the determinants of the origins of tool use. He observes that insight may be more easily explained through associative principles acquired during critical learning periods. However, he admits that certain instances, such as box stacking in chimpanzees, are hard to explain without invoking insight and that the controversy is unlikely to go away (Beck, 1980).

Much of the controversy over insight is the use of the term as a causal explanation of behavior. Some have even stated that using the word insight is the same as “invoking magic” (Kloc, 2009, June). Shettleworth (2010b) argues for the automatic chaining explanation of insight as exemplified by the “insightful” pigeon (Epstein, et al., 1984). She warns of the tendency to accept insight as an explanation of behavior over “killjoy” explanations based on elementary mechanisms of behavior (Shettleworth, 2010a).

Kacelnik (2009) is also wary of using the term insight as a causal explanation. His own research in which a New Caledonian crow bent a wire into a hook to acquire food is often used as an example of insight (Weir, et al., 2002). But Kacelnik and his colleagues are more interested in determining the mechanisms behind the behavior. They replicated an insightful problem solving task in rooks (Bird & Emery, 2009a) using New Caledonian crows (von Bayern, Heathcote, Rutz, & Kacelnik, 2009). The task consisted of dropping a rock through a tube onto a platform that then released and dropped a worm through a slot. They found that unless the crows had experience with the platform mechanism by pushing it with their beaks, they would not drop a stone onto it. Kacelnik finds that “use of insight in animal behavior in an explanatory, causal role is as baffling as the problem that is supposed to solve” (Kacelnik, 2009, p. 10072) and suggests that the term insight be left alone.

Is insight a causal explanation? I argue that the problem is inferring that the use of the term "insight" implies a causal explanation as opposed to a descrition of behavior. Notably, later in his career, Köhler, stated that he never meant the term insight to be an explanation but rather a description of the chimpanzee's behavior (Köhler, 1947). Thorpe's commonly used definition "the sudden production of a new adaptive response not arrived at by trial behaviour or the solution of a problem by the sudden adaptive reorganisation of experience" (Thorpe, 1963, p. 100) does not imply causality. Kandula and Shanthi's problem solving behavior fits Thorpe's definition of insightful learning.

Possible Causal Explanations for Insight

Although Thorpe's definition has been used as a standard, some have found it lacking because it does not address the possible cognitive processes underlying insight (Bird & Emery, 2009b). This lack of an explanatory definition has allowed for different possible causal explanations for insight. Epstein, et al.(1984) proposed that insight-like behavior was the result of automatic chaining of previously reinforced behaviors. They also admit that the solution may be devised through covert behavior. Millikan (2006) refers to this style of reasoning as "trial and error in thought" a perceptual capability which we may share with animals. Emery and Clayton (2004) suggest a role for imagination in insight. They define imagination as "the process by which scenarios and situations that are not currently available to perception are formed in the mind's eye" (Emery & Clayton, 2004, p. 1906). In this framework, insight can be seen as process by which the situation is mentally acted out in preparation for the external behavior (Bird & Emery, 2009b). In his presentation at a recent animal behavior conference, Gray (Gray, 2011) admonished scientists for the use of insight as a behavioral term. In the same lecture, referring to his own work on metatool use in New Caledonian crows (Taylor, et al., 2010), Gray stated that he thought that this study indicated that the birds were capable of creating a "mental scenario" in order to solve the problem.

From a different perspective, Gallistel, Fairhurst, and Balsam (2004) have proposed a model of learning based on evidence gathering in which an animal changes abruptly to a different strategy when evidence exceeds a decision threshold. This model has been supported in rats by demonstrating neurological evidence corresponding to the sudden shifts in behavioral strategies as seen in insightful problem solving. The authors concluded that their results "support the idea that rule learning is an evidence based decision process perhaps accompanied by moments of sudden insight" (Durstewitz, Vittoz, Floresco, & Seamans, 2010, p. 438).

Human Neuroscience and Insight

One method to investigate causality in insight is through neuroscience. Apart from the research cited above, there has been little neurophysiological research into insight conducted on animals (particularly elephants). However, research into insight in human beings has been conducted from the perspective of neuroscience using functional magnetic resonance imaging (fMRI) and electroencephalography (EEG) (Kounios & Beeman, 2009). One area of the brain that is implicated in insight solutions is the anterior cingulate cortex (ACC) (Aziz-Zadeh, et al., 2009; Kounios & Beeman, 2009). The ACC appears to have a role in resolving conflicts in information processing (Botvinick, Cohen, & Carter, 2004). It is thought that its role in insight is to monitor for "weakly activated subconscious solutions" (Kounios & Beeman, 2009). Insight solutions also involve the prefrontal cortex, which seems to be involved in the evaluation and metacognition of an insight problem rather than the solution itself (Aziz-Zadeh, et al., 2009). Insight may also be affected by differential activation of the left and right hemispheres. The right hemisphere is able to maintain diffuse activation of distant associations and solution relevant concepts. At the same time, the left hemisphere, which has stronger activation in problem solving, may have formed a false solution. Insight arrives upon coordination of the two hemispheres (Bowden, Jung-Beeman, Fleck, & Kounios, 2005). Interestingly for a concept known as insight, during solutions in these studies there is lowered activity in the occipital or visual cortex. It is thought that this may be the equivalent of closing one's eyes to concentrate on a problem (Kounios & Beeman, 2009).

Unfortunately for the purpose of comparative studies, the insight problems given in these human cognitive studies are word problems such as anagrams given visually (Bowden, et al., 2005) or verbally (Jung-Beeman et al., 2004). So insight indicated by activation of the language centers in the temporal lobes (Jung-Beeman, et al., 2004) may not find parallels in the animal brain. When we have the capabilities to do similar in vivo studies on animal brains, it may finally be possible to find causal explanations for insightful problem solving.

The Role of Experience in Insight

It has been thought that Köhler underestimated the role of experience in his chimpanzees' insight solutions, but he was very much aware of its importance (Rumbaugh & Pate, 1984).

> I am far from asserting that the animals tested in the second chapter have never had a stick, or anything like that, in their hands before the experiment. On the contrary, I take it for granted that every chimpanzee above a certain very low age has had some such experience; he will have seized a branch in play, scratched on the ground with it and so on (Köhler, 1925, p. 213).

The concept of insight in Gestalt psychology is that one is breaking functional fixedness. Functional fixedness, or the idea that items can serve only a certain use, requires that the individual has had previous experience with the individual objects that constitutes the problem (Mayer, 1995).

Birch (1945a) conducted an experiment to examine the effects of experience on insightful problem solving. Six captive born chimpanzees were given a food acquisition problem using a rake made of sticks. Only two solved the problem, each using a different method. Over the next three days, the chimps were provided with sticks. They played with the sticks in their enclosure. When they returned to the problem, all six chimpanzees solved the problem within 20 seconds. Birch considered previous experience a crucial aspect of insightful problem solving. The solution to the problem is devised from materials provided by experience, and any analysis of an insightful performance that ignores this is invalid.

Some may be concerned that the food acquisition problem in Experiment 5 utilized objects, the cube and the tire, with which the Kandula had prior experience. But according to Birch's formulation, the use of these items was a crucial part of Kandula's successful solution to the problem. Practicality dictated their choice. It is extremely difficult to devise a platform that would support an elephant's weight that will be light enough for people to move into position. Taking that into consideration, Kandula had never used either item in this research to move to stand on to reach for an item. The butcher blocks in Experiment 8 were novel items, but Kandula was given one session to gain experience with one of them.

Why Only Kandula?

The question remains as to why the two older females did not solve the tool use problem in Experiment 5. One answer could be sex differences. Males may also be more inclined to individual investigation and initiative since eventually they spend more time alone away from other elephants (Moss, 2000). A study on problem solving in gibbons investigated the effects of experience and sex differences in insightful problem solving (Cunningham, Anderson, & Mootnick, 2011). In a food raking problem, the researchers found that experience with the rake had no effect on the problem solving abilities of the males. However, rake experience greatly benefitted the females. They hypothesize that females may be more cautious in their explorations of new situations because of the dangers to offspring. The experience with the rake served to reduce the novelty of the problem situation.

Wild capuchin monkeys engage in nut cracking using rocks as tools. This behavior is seen much more in adult males than females. However, sub-adult females engage in the practice more than sub-adult males (Ottoni & Mannu, 2001). It is unclear if sex was a factor contributing to the behavioral differences found in the elephants in this study. However, all the elephants manipulated sticks in other circumstances and Shanthi exhibited insightful problem solving in the chain problem.

Age differences may also account for the discrepancy in problem solving between Kandula and the other elephants. Juvenile capuchin monkey exhibited more instances of tool use for nut cracking than either sub adults or adults (Ottoni & Mannu, 2001).Young elephants tend to be more manipulative and playful (Moss, 2000). There is some evidence that older elephants (over 20) do not perform as well as younger ones in cognitive tasks (Nissani, et al., 2005). The older elephants, because of the physical impairment of their age, may have been hesitant to step up on the platform unless commanded. However, Shanthi's performance in the chain problem does not suggest an age difference in insightful problem solving.

A third reason may be differences in motivation. Birch (Birch, 1945b) tested the effects of motivation on insightful problem solving by varying the number of hours of food deprivation in chimpanzees. He found that the chimpanzees with an intermediate amount of deprivation performed better than those with either more or less deprivation. In general, the female elephants (particularly Ambika) in this study are less food motivated than Kandula, as can be seen by the amounts of reaches and sniffs toward the food in the different experiments (Figures 6 & 8). However, all the elephants attempted to obtain the food at some point during the sessions.

Finally, it is possible that, by chance, I found one of a minority of elephants that has the capabilities to problem solve with tools. There is very little statistical possibility that Kandula could be one of the only elephants with this ability. Kandula's performance can serve as an existence proof, documenting this ability in at least one member of and elephant species. Therefore I consider his performance in these experiments as evidence for insightful problem solving in this species.

Future Research

This research was conducted using a very small sample size: the elephant population of convenience at the National Zoo. To replicate the results of this study and verify the hypotheses, it will be necessary to conduct this research on a much larger number of elephants in zoos where these studies can be conducted under controlled conditions. It would also be advantageous to run these tests on African elephants to ascertain species differences in cognition. Further problem solving research could also be conducted on untrained wild elephants. Different experimental protocols would need to be devised accommodate the difficulties of working with wild elephants.

In continuing to work with Kandula, I would like to test if he is capable of metatool use. Food would be hung overhead out-of-reach. The cube would be place on the opposite side of the bars of his enclosure. Sticks would be provided in the enclosure. The experiment would test if Kandula would use the stick to acquire the cube to stand on to obtain the food. This cognition has been seen in New Caledonian crows (Taylor, et al., 2010; Taylor, Hunt, Holzhaider, & Gray, 2007). Solving this problem in this manner would also help to confirm the hypothesis of stick use in relation to food. In that case, Kandula would show that he used sticks to acquire an object to attain food but would not use the sticks to acquire the food.

While observing the elephants over the course of this study, it became clear that they have a sense of leverage. They were often seen to place sticks in door jambs under other objects and use them in a prying motion. Kandula used a log as a lever to pull down a bolted pillar supporting the cables of his enclosure (12ashley02, 2009). The amount of this behavior seen is curious because neither Chevalier-Skolnikoff and Liska's (1993) extensive review elephant tool use nor the latest edition of *Animal Tool Behavior* (Shumaker, et al., 2011) mention elephants using tools. The latter work mentions use of leverage in primates, carnivores, birds and gastropods, but finds no examples of the technique in elephants. This area represents an open field of research to better understand cognition in elephants.

Research Implications

The history of man's involvement with elephants goes back to ancient history. Elephants have been used as trained work animals for over 4,000 years (Sukumar, 2003). Yet, our knowledge of cognition in these species is sorely lacking (Byrne, et al., 2009). Research such as the studies discussed in this dissertation are vital for our scientific knowledge of elephants which, in turn, can inform our treatment of elephants in captivity and the wild, aid in conservation, and enlighten us about the evolution of intelligence.

From the standpoint of cognitive research, attempting to understand how the mental processes of an animal as different from us as the elephant can help expand the reach of comparative psychology (Bates, Poole, & Byrne, 2008). The nearest relatives to the elephant are manatees and rock hyraxes (Sukumar, 2003). Elephants are much farther from us evolutionarily than other primates, until recently the most common cognitive subject. Our last common ancestor with elephants was ~100 million years ago. In comparison, our last common ancestor with mice was ~91 million years ago (Goodman et al., 2009). Expanding research to animals such as the elephant can specify the commonalities of cognitive processes while showing how cognition may differ among species. This line of research has already been productive as exemplified by studies on means-end recognition (Irie-Sugimoto, et al., 2008), quantity judgement (Irie-Sugimoto, et al., 2009), mirror self-recognition (Plotnik, et al., 2006), and cooperation (Plotnik, et al., 2011).

The use of cognitive studies on captive elephants can not only serve to increase our knowledge of their abilities but aid in welfare of the animals in captivity. A current concern for captive animals is environmental enrichment. Environmental enrichment has been defined as “an animal husbandry principle that seeks to enhance the quality of captive animal care by identifying and providing the environmental stimuli necessary for optimal psychological and physiological well-being” (Shepherdson, 1998). The Association of Zoos and Aquariums (AZA) mandates that all accredited American zoos provide regular and frequent enrichment to their entire animal collection (AZA, 2011). One common method of providing enrichment is through the use of puzzle feeders, a device in which the animal has to solve the problem of attaining food. Puzzle feeders have been used as enrichment for many species including parrots (Field & Thomas, 2000), giant pandas (Hare et al., 2003), marmosets (Roberts, Roytburd, & Newman, 1999), and elephants (Tresz, 2006). Puzzle feeders providing juice have been employed to study spontaneous tool use in chimpanzees (Morimura, 2003). Problem solving research in the zoo setting can help to devise and improve enrichment items such as these. In turn, studying the animal’s use of the puzzle feeder can provide valuable information about problem solving. Both the fields of animal welfare and cognitive research benefit from the exchange.

The goals of zoos to educate and interest the public in animal conservation can be enhanced through communication of the details of cognitive research conducted at the zoo

(Plotnik, et al., 2009). The current research in the elephant yard was conducted in front of the public. The fascination of the spectators was evident in their interest and verbal comments on how intelligent the elephant appeared. One can hope that they will look at elephants with new eyes and be more involved with their conservation. Cognitive research in the zoo setting benefits science, conservation, animal welfare, and the public at large.

In terms of conservation, it is becoming increasingly crucial to understand elephant cognition. One of the greatest conservation challenges facing elephants is human-elephant conflict. As human populations expand into elephant habitat, both species compete for land and food. Crop raiding by elephants can end in the death of people, elephants, or both (Kiiru, 2008). This problem is growing increasingly worse. In India alone, between 1980 and 2000, 150-200 people lost their lives each year (Sukumar, 2003). According to Indian government figures, in the last three years, a total of 1090 people have lost their lives, about one person daily (SAPA, 2010). To save both elephants and people, it is necessary to understand the elephant’s cognitive behavior. For example, if a farmer is creating a barrier to keep elephants from crops, it might be important to know that the elephant may drag something over to stand on to get over the barrier. Elephants have been seen to drop tree trunks on fences and pile branches on roads, apparently to block access (Chevalier-Skolnikoff & Liska, 1993). Elephants have been seen pushing wires on electric fences apart with their tusks and pushing the younger elephants through the gap (Kiiru, 2008).

Behavioral research has been conducted to find solutions to help both humans and elephants in these situations. For example, researchers observed that elephants are afraid of bees and avoided trees in which there were nests (Vollrath & Douglas-Hamilton, 2002). Playback experiments were conducted to show that the sound of bees would make elephants run away

(King, Douglas-Hamilton, & Vollrath, 2007). Finally, fences were constructed with beehives as a deterrent for crop raiding elephants and found to be successful in keeping the elephants from crop raiding (King, et al., 2007). Another example of using behavioral research to find an elephant deterrent is O'Connell's (2007) attempts to use the elephant's seismic communication to deter crop raiding through broadcast alarm calls.

My research points to the importance of olfaction in the elephant's food foraging behavior. In the wild, elephants seek trees with the greatest nutrient value. Trees with lesser nutrient value are knocked down to obtain the more nutritional parts. The nutrient value is indicated by nitrogen compounds in the earth and excreted in the elephants' urine (Pretorius et al., 2011). The elephants detect the nitrogen rich areas through their sense of smell (Pastor, 2011). In Sri Lanka, the elephants raid rice paddies. They arrive just as the rice is ready to be harvested and can wipe out an entire crop. It is suspected that they sense the ripening rice through their olfactory sense. Investigations are being made into masking the chemosensory signals of the rice to keep the elephants away (Santiapillai & Read, 2010).

Another avenue for cognitive research in conservation is addressing cognitive difficulties in elephants that may be caused by man's encroachment, hunting and ivory poaching. (Bradshaw & Schore (2007) note that cognitive problems caused by stress created by human disturbance may be causing dangerous abnormal behavior in elephants, such as killing rhinoceros. They call for an interdisciplinary approach to solve these problems, combining psychology, neuroscience, and ethology to address these problems. Cognitive research in elephants, such as studies investigating the determinants of tool use and problem solving, can play a valuable role in elephant conservation by increasing our knowledge of their behavior and providing methods for us to share territory for the mutual benefit of both elephants and humans.

Appendix: List of tool and tool-like behaviors observed during the study

Behavior	Definition	# seen in each elephant			Comments
		A	K	S	
Tool use					
Blow	Elephant emits air through its trunk towards a hanging food item. Presumable purpose: to knock down the food item.	2	66	2	
Brush Manufacture	Shanthi beat a piece of bamboo against the floor until the end was splayed and then used the splayed end to rub against her body. Presumable purpose: body care.			1	
Dust bathe	Elephant throws dirt or hay on its back. Presumable purpose: body care.	197	119	484	
Scratch	Elephant rubs stick against body. Presumable purpose: body care.	14	12	49	
Throw	Elephant uses trunk to project an object or dirt. Presumable purpose: to knock down item or threat.		1	6	Kandula threw a piece of bamboo at out-of-reach food from his stall. Shanthi threw dirt at a squirrel, at experimenters on the roof of the elephant house, and twice threw sticks at hanging food.
Tub lean	Ambika moves aluminum elephant tub until it is on its side under her ventral side, between all four legs, and leans on it. Presumable purpose: weight support.	10			Ambika did this once in each session in which the behavior was seen.
Water spray	Elephant draws water into trunk and then emits it on body. Presumable purpose: body care.	1			

Behavior	Definition	# seen in each elephant A	K	S	Comments
Tool-like use					
Air play	The elephants placed their trunks in fire hoses provided as enrichment items and inflated them repeatedly.		1	1	
Hammer/play	Kandula struck a stick into the ground using the side of his mouth until it was standing vertically and then proceeded to play with it using his body, trunk, head, and tail.		1		
Hit	Elephant strikes ground, walls, and other stationary objects with stick.	19	380	154	
Hit toy	Elephant hits hanging enrichment item with stick.		1	4	
Plow	Elephant pushes stick ahead of itself with end on floor or in ground.		13		
Pry	Elephant places a stick in crack around door and uses it as a lever.	4	104	2	
Sweep	Elephant holds stick on one end and scrapes floor with other end in a sideways motion.	2	6	2	
Throw on back	Elephant takes a stick or other item and projects it onto its dorsal side with trunk.	10	11		
Totals		259	721	705	

Note. The table lists all instances of either tool or tool-like behavior observed during the course of the study. Tool behavior is defined as the use of an object (including air or water) to affect another object with a presumable purpose. Tool-like behavior is defined as the use of an object in a similar manner but with no obvious presumable purpose (possibly play). Uses of objects to stand on for food acquisition previously discussed in the experiments are not included in the table. Sessions conducted in the interior of the elephant house in which sticks were provided are included. These sessions were each approximately 20 minutes long: Ambika-21 sessions, Kandula-20 sessions, Shanthi-21 sessions. Outdoor experimental sessions included: Ambika-16 sessions, Kandula-54 sessions, Shanthi-16 sessions. An additional 26 outdoor sessions was conducted with both Ambika and Shanthi together for approximately 30 minutes. Approximate total amount of time included in the table for each elephant: Ambika and Shanthi – 25 hours, 20 minutes, Kandula – 24 hours, 40 minutes. Air play and Shanthi throwing dirt at experimenter on roof were observed outside of experimental sessions. Number seen in each elephant refers to the number of instances of behavior observed. Multiple uses of a behavior in quick succession (i.e. hitting an object multiple times) are treated as one instance of the behavior. A=Ambika; K=Kandula; S=Shanthi.

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