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Object Permanence in Asian Elephants (Elephas maximus)

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Object Permanence in Asian Elephants (*Elephas maximus*)

by

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Abstract

Examining findings across a range of cognitive tasks, Asian elephants *(Elephas maximus)* appear to demonstrate many advanced cognitive skills. Object permanence tests provide a way to contextualize the elephant perspective, examining behaviors demonstrated at the intersection of vision, cognition, and decision-making. Building on existing research, this study examined adult elephant performance in a series of six visual tasks investigating object permanence. The methodological approach followed Piaget's experimental model and examined elephant performance in both visible and invisible object displacement conditions. Visible tasks were administered first with object displacements presented according to a successive increase in number: first, single displacement, second, double displacement, and third, triple displacement. The following invisible displacement tasks replicated this successive displacement test order. This study predicted elephants would successfully apply visual perception to demonstrate object permanence. Study outcomes supported initial predictions that elephants can use vision to solve visible object displacement tasks concordant with Piaget's stage 5, and also, that elephants possess the cognitive skills to conceptualize object permanence. Elephants performed significantly above chance in the triple invisible displacement task, challenging the expected ordering of task demands. Outperforming expectations in invisible displacement tasks, elephants demonstrate advanced object permanence defined by Piaget's stage 6. Confronted with abstract and incomplete information, elephants appear able to infer the appropriate solution to a complex problem.

Keywords: Elephants, Piaget, cognition, object permanence, intelligence, vision

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Introduction

Object permanence is the ability to conceptualize that an object concealed from view remains in the environment. A capacity for object permanence is examined in controlled experiments according to a hidden object search paradigm (Barth & Call, 2006). In these tasks, disappearance is defined by physical concealment, rather than an object moving to a visually imperceptible distance (Gibson, Kaplan, Reynolds, & Wheeler, 1969). Object permanence demonstrates advanced cognition, and requires coordinated perception, attention, working memory, motivation, and mental representation to find a hidden object (Pepperberg & Funk, 1990). This study examines object permanence in Asian elephants *(Elephas maximus)* according to six object displacement tasks. In elephants, object permanence tests provide a way to explore the intersection of vision, cognition, perspective-taking and decision-making behavior.

One goal of this research is to learn more about the range of sensory information elephants can use to navigate the physical world. Elephants, like all species, apply sensory perception to detect stimuli and construct a representational understanding of their environment based on individual interpretation. The elephant's use of vision is not well understood and research suggests elephants largely rely on olfaction to process information (Plotnik, Shaw, Brubaker, Tiller, & Clayton, 2014). Study findings will contribute to an understanding of applied vision in cognitive tasks, convergent cognitive evolution across species, and more effective strategies for elephant conservation.

In the 20th century, the developmental psychologist Jean Piaget examined ontogenetic development of object permanence in children. Piaget's classical, or constructivist theory, proposes that object permanence develops in conjunction with human cognitive development in the sensorimotor stage, from infancy to age two (Piaget & Cook, 1952). Children acquire knowledge about the physical world to construct an individual perception of their environment and apply it to decision-making (Piaget & Cook, 1952). Piaget's research examined two primary object displacement paradigms – visible object displacement and invisible object displacement – that are applied to examine whether cognitive skills provide for object permanence (Piaget & Cook, 1952). Objects can be hidden once or multiple times, for example, in single displacement, double displacement, and triple displacement tasks.

According to Piaget, visible displacement tests establish whether a subject possesses a basic capacity to understand object permanence (Piaget & Cook, 1952). Visible displacements require a subject to observe an experimenter hide, or displace, an object, then identify the object's hidden location. The methodological distinction between visible and invisible displacement is demonstrated at the outset of an invisible displacement test, when an object is only briefly visible as it is placed in an opaque container preceding displacement. During a displacement, an object remains concealed in the container while displacements are performed with the container. A subject must associate an object with the cues provided by the container displacement to infer the location of a hidden object (Piaget & Cook, 1952). According to Piaget's comparative assessment of the two displacement paradigms, invisible tasks examine advanced object permanence concepts, representing higher cognitive demands than visible tasks (Piaget & Cook, 1952).

Piaget's work contextualizes object permanence in age-based stages alongside emergent cognitive skills. From 0 to 8 months old, infants do not demonstrate object permanence. Basic environmental awareness develops in early stages, supporting a child's capacity for object permanence: stage 1, 0 – 1 months, stage 2, 1 – 4 months, and stage 3, 4 – 8 months (Corman & Escalona, 1969). By stage 5, children demonstrate success in visible displacement tests, and in stage 6, children can solve invisible displacement tests (Piaget & Cook, 1952). Table 1 outlines object permanence development according to Piaget's theory.

Table 1

Piaget's early childhood sensorimotor stage theory, detailing development in stages 4, 5 and 6 to provide a developmental context for object permanence in humans.

Stage	Month/s of Age	Cognitive Development	Object Permanence
4	9 - 12	Can conceptualize physical properties of an object	Unsuccessful object search
5	12 - 18	Can apply reasoning using direct object cues	Successful visible displacement object search
6	18 - 24	Can apply reasoning using direct and indirect object cues	Successful visible displacement object search; Successful invisible displacement object search

Piaget's framework is used to examine object permanence in other species to assess development and comparative cognition (Barth & Call, 2006). In animals, object permanence is considered an adaptive trait (Ujfalussy, Miklósi, & Bugnyar, 2013). Object permanence shows mental flexibility because it facilitates decision-making and allows animals to dynamically adapt to changes in the environment (Shumaker, Palkovich, Beck, Guagnano, & Morowitz, 2001). Object permanence is critical to enhancing foraging, communication, and predator detection. In the wild, animals are confronted with dynamic information in ever-changing landscapes (Schulte, 2000; Barth & Call, 2006).

Sustained visual attention is most important when tasks involve multiple displacements. Inattention compromises the ability to recognize that the object is being hidden more than once, limiting successful decision-making. Inattentive individuals are likely to fail because they consider the object to be in an initial hiding spot. Motivation is also critical to object permanence task success. While no single causal mechanism can account for all motivating factors, the absence of motivation might suggest an individual does not understand the object permanence concept. Motivation might be regulated by level of natural curiosity, interest, and or level of desire to interact with the hidden object. In a successful test, obtaining a salient reward for a correct search serves as positive reinforcement, motivating sustained attention and interest.

Memory is critical to the capacity for object permanence. Observed events must be recalled accurately in order to identify where an object was (Barth & Call, 2006). The capacity to solve tasks is therefore dependent on short-term memory processes of encoding and retrieval. In object permanence tasks, subjects may fail to demonstrate conceptual understanding of object permanence if working memory is limited. Wrong decisions might be interpreted as a failure to demonstrate object permanence, though a more direct cause of failure might be working memory limitations.

Literature Review

Object permanence provides species with realistic expectations based on events in their environment, enhancing species survival (Ujfalussy et al., 2013). For individuals, this understanding serves to enhance decision-making because individuals can maximize their energy output by concentrating on changes in the environment which may harm or benefit their survival (Nawroth, von Borell, & Langbein, 2015). The capacity for object permanence has been demonstrated in non-human primates, birds, and domesticated animals. However, research shows species-level success on object permanence tests varies across visible and invisible displacement task paradigms. Some species show visible displacement success, others show visible and invisible displacement success while other studies are in conflict about these capacities in a single species.

Great apes and some monkeys demonstrate a capacity to solve all visible displacement tasks, among them, gorillas (*Gorilla gorilla)*, chimpanzees (*Pan troglodytes*), orangutans (*Pongo pygmeaus*), bonobos (*Pan paniscus*), and squirrel monkeys (*Saimiri sciureus*) (Call, 2001; Barth & Call, 2006; De Blois, Novak, & Bond, 1998). Other species also demonstrate success in this paradigm, including, cats (*Felis catus)* (Triana & Pasnak, 1981; Doré, 1986) and four lemur species (*Eulemur fulvus rufus*, *Eulemur mongoz*, *Lemur catta*, and *Hapalemur griseus)* (Deppe, Wright, & Szelistowski, 2009). Research demonstrates variability between and within species in invisible displacement experiments. However, mixed success may be the result of the nature of the task, as experiments also examine methodologies that apply rotations and/or transposition tasks, in addition to experiments using Piagetian methodology. For example, in a single invisible displacement transposition task chimpanzees and bonobos outperformed gorillas and orangutans (Barth & Call, 2006).

Species demonstrating inconsistent success on invisible displacement tests include: gorillas (Barth & Call, 2006), chimpanzees (Call, 2001; Barth & Call, 2006; Collier-Baker, Davis, Nielsen, & Suddendorf, 2006), bonobos (Barth & Call, 2006), orangutans (Call, 2001; De Blois et al., 1998), dogs (*Canis familiaris*) (Gagnon & Doré, 1993; Miller, Gipson, Vaughan, Rayburn-Reeves, & Zentall, 2009; Collier-Baker, Davis,

& Suddendorf, 2004), and magpies (*Pica pica*) (Pollok, Prior, & Güntürkün, 2000). Rhesus macaques (*Macaca mulatta*) (De Blois & Novak, 1994; Filion, Washburn, & Gulledge, 1996), cotton top tamarins (*Saguinus Oedipus)* (Neiworth, Steinmark, Basile, Wonders, Steely, & DeHart, 2003) and four species of psittacine birds (*Psittacus erithacus, Ara maracana, Melopsittacus undulatus, Nymphicus hollandicus)* (Pepperberg & Funk, 1990) consistently perform well on visible and invisible displacement tasks, suggesting advanced object permanence.

Squirrel monkeys (De Blois et al., 1998) and lemurs (Deppe et al., 2009) fail all invisible displacement tests. Table 2 provides a non-exhaustive list of species according to findings in object permanence studies. Information is categorized according to success in visible displacement and invisible displacement tests, with ‘X’ used to note success. Additional notations are provided to identify study designs where invisible displacement was examined in rotation conditions (an apparatus rotates prior to a choice) or transposition conditions (a subject changes spatial location before a choice). Piaget’s invisible displacement experiments were not administered with rotations or transpositions (for details, see the methodology section below). In Table 2, invisible displacement studies with an ‘X’ notation indicate that a study applied testing according to Piaget’s methodology. Other relevant condition details are noted as well.

Table 2

A non-exhaustive review of stage 5 and stage 6 object permanence among non-human animal species tested for object permanence.

Species	Reference	Visible Displacement (Stage 5)	Invisible Displacement (Stage 6) Rotation (R) Transposition (T)
Canis familiaris	Miller, Gipson, Vaughan, Rayburn-Reeves, & Zentall, 2009	X	X (R)
	Gagnon & Doré, 1993	X	
	Collier-Baker, Davis, & Suddendorf, 2004	X	X
Felis catus	Triana & Pasnak, 1981	X	X Disputed, Doré, 1986
	Doré, 1986	X	
Gorilla gorilla	Barth & Call, 2006	X	X (T)
Pan paniscus	Barth & Call, 2006	X	X (T)
Pan troglodytes	Collier-Baker, Davis, Nielsen, & Suddendorf, 2006		X Single Displacement
	Call, 2001	X	X
	Barth & Call, 2006	X	
Pongo pygmaeus	Barth & Call, 2006	X	
	Call, 2001	X	X
	De Blois, Novak, & Bond, 1998	X	X
Saimiri sciureus	De Blois, Novak, & Bond, 1998	X	
Saguinus oedipus	Neiworth, Steinmark, Basile, Wonders, Steely, & DeHart, 2003	X	X
Macaca mulatta	Filion, Washburn, & Gulledge, 1996		X
	De Blois & Novak, 1994	X	X
Eulemur fulvus rufus, Eulemur mongoz, Lemur catta, Hapalemur griseus	Deppe, Wright, & Szelistowski, 2009	X	
Psittacus erithacus, Ara maracana, Melopsittacus undulatus, Nymphicus hollandicus	Pepperberg & Funk, 1990	X	X
Cacatua goffini	Auersperg, Szabo, von Bayern, & Bugnyar, 2014	X	X
Pica pica	Pollok, Prior, & Güntürkün, 2000	X	X Some tasks

While elephants have not been tested for object permanence, a review of elephant cognition literature suggests elephants possess the cognitive skills associated with object permanence. In captivity and in the wild, elephants demonstrate tool use, a capacity linked with flexible intelligence also demonstrated among primate and corvid species (Irie-Sugimoto, Kobayashi, Sato, & Hasegawa, 2008). Elephants use branches as fly swatting tools and modify branches to maximize their swatting efficacy (Hart, Hart, McCoy, & Sarath, 2001). Tool use demonstrates the ability to apply a flexible approach to problem solving to attain a specific outcome, which may also be necessary for stage 6 of object permanence (Tomasello & Call, 1997).

Alongside tool use, captive elephants demonstrate insightful problem solving, manipulating novel objects to gain access to unreachable food. Foerder, Galloway, Barthel, Moore III, and Reiss demonstrated this in their 2011 study conducted at the National Zoological Park in Washington, D.C. When food was located beyond an elephant's trunk reach, an elephant moved a novel object and used it as a platform to access the food. This shows an adaptive approach to problem solving and behavioral flexibility.

Wider skills are demonstrated in accordance with goal-oriented behavior in means-end tasks and cooperative social tasks (Irie-Sugimoto et al., 2008; Plotnik, Lair, Suphachoksahakun, & De Waal, 2011). Means-end tasks investigate goal-directed behavior and how such behavior relates to problem solving (Irie-Sugimoto et al., 2008). Means-end tasks were originally examined in Piaget's child development studies and success demonstrates an understanding of the relationship between a support apparatus and a desired object. An individual must manipulate a support apparatus to bring an object into reach. Elephants demonstrated success in this task (Irie-Sugimoto et al., 2008; Highfill, Spencer, Fad, & Arnold, 2016).

Elephants are also considered socially and emotionally intelligent (Bates, Lee, Njiraini, Poole, Sayialel, Moss, & Byrne, 2008; Garstang, 2015). In the wild, female elephants maintain complex social networks and demonstrate emotional intelligence in these cooperative societies (Schulte, 2000). In captivity, elephants navigate social relationships with conspecifics and also manage relationships with humans. Specifically, elephants demonstrate complex social intelligence demonstrating altruistic behavior and empathy for conspecifics (Bates et al., 2008; Plotnik, De Waal, & Reiss, 2006).

Possessing diverse cognitive capacities provides elephants with ecological advantages adapted to benefit species survival (Garstang, 2015; Barth & Call, 2006). In the wild, Asian elephants forage in densely forested areas seeking vegetation to meet daily nutrition requirements. However, while elephants must meet these daily needs, elephant foraging activities are largely based on non-visual sensory information (Garstang, 2015), perhaps one ecologically valid reason explaining why vision in elephants has not been widely researched. Elephants appear to use vision to interpret body language signaling provided by conspecifics, specifically to identify ear, tail, and trunk-related information (Garstang, 2015). Asian and African elephants use acoustic information to communicate across wide distances using infrasonic, low frequency sound (Garstang, 2015; Langbauer Jr, 2000). Among captive elephants, research suggests that they primarily rely on olfaction to detect and process sensory information provided in their environment (Plotnik et al., 2014). However, Polla, Grueter, and Smith (2018) found elephants succeeded in a visual task examining discrimination between familiar and unfamiliar humans.

Wild and captive elephants demonstrate a range of cognitive abilities and specifically demonstrate, tool use, goal-oriented behavior, insightful problem solving, and means-end task success (Hart et al., 2001; Foerder et al., 2011; Highfill et al., 2016; Plotnik et al., 2006). These skills suggest elephants possess the ability to solve problems in their environment, which may extend to the capacity for object permanence. Accordingly, this study will examine elephant cognition in a series of visual object permanence tasks.

This study predicts elephants will solve visible displacement tasks, associated with Piaget's stage 5 object permanence. Tasks will focus on vision to examine the elephant's capacity for object permanence. This study predicts elephants will demonstrate the capacity to observe and process, and recall information to identify the hidden location of a food reward. Building on elephant cognition research, this study will explore object permanence in a visual context to extend scientific understanding of vision within an elephant's perceptual world.

Materials and Methods

Subjects

Six captive adult female Asian elephants (*Elephas maximus*) were the subjects in this study. Data collection occurred between January 2018 and April 2018. The Golden Triangle Asian Elephant Foundation (GTAEF) provided access to subjects: Beau (age 39), Dah (age 16), Lanna (age 30), Pluem (age 29), Prae (approximately age 31), and Yui (approximately age 26). All aspects of elephant care, including, food, shelter, mahout (elephant keeper) housing, and on-site veterinary care were provided by GTAEF in partnership with the Anantara Golden Triangle Elephant Camp and Resort. During data collection, subjects' regular diet included pineapple fronds, sugarcane, bananas, and foraged vegetation. This study was reviewed and approved by Hunter College's IACUC.

Subjects and their mahouts resided at the elephant camp on the premises of the Anantara Resort in Chiang Saen, Chiang Rai, Thailand, a short distance from the test site. During testing, subjects continued to provide elephant experiences to Anantara guests. This included interactive elephant education activities and engagements with tourists under GTAEF supervision at the Anantara Resort and the nearby Four Seasons Tented Camp Golden Triangle.

Mahouts – often the elephants' owners but, for the purposes of this study, their handlers – were instructed not to feed elephants before morning test sessions. Heightened food motivation enhanced subject interest in testing and helped maintain subject attention. Test sessions were scheduled in 30-minute increments between 7:00 a.m. and 8:30 a.m. Subjects generally completed a single test session within 15-30 minutes.

A single test session comprised twelve trials, eight were test trials and four were control trials (see below for details). The first three trials presented in a test session were all test trials. Control trials were assigned randomly to the remaining nine test session spots. The number of consecutive control trials was limited to two. When control trials were assigned three or four consecutive spots in a session, randomizations were repeated.

Unique to each subject and test session, data sheets created in advance of testing detailed all pre-randomized assignments; a sample data sheet is provided in Figure 1. Randomizations included: the presentation order of tests and controls in the twelve trials, the buckets assigned to each trial displacement, and a corresponding order of bucket lid placement. A data assistant recorded the date, time, weather, subject name, task type, test session number, personnel, and personnel roles on a data sheet.

Figure 1

Data sheet used for subject Pluem in task 3 (TVD), test session 4. Randomized bucket and lid assignments are typed with notes and choices recorded by hand. Date format is d/m/yy.

T/C	T/C Results	Crit Met? Y/N	# T correct needed next session to meet criterion?	Training needed before next session? Provide details if yes
T	4 /8	6 /16	6 /8	
C	2 /4			

Subj: PLUEM Date: 6/3/18 Start Time: 8.00 Weather: clear

Condition & Session: TVD 4 Individuals Present/Roles: Fene (Ex), Yvie (D), Anne (C)

Criterion met if # correct T combined with prior session = 8 /8

Tests & Controls		Baited Bucket	Lid Placement (ABC)	Choice (Y/N)	1st Bucket Choice	2nd / 3rd Bucket Choices	Notes
T	1	BCA	BCA	Y	A		
T	2	BAC	BAC	Y	C		
T	3	ABC	CBA	Y	C		
C	4	A	ACB	N	C	B	
T	5	ACB	ABC	N	C		
C	6	C	CBA	Y -	C		
T	7	CAB	CBA	Y	B		
T	8	CBA	ACB	N	B		
T	9	BCA	CBA	N	B		
T	10	CAB	ABC	N	A	B	
C	11	B	ABC	Y -	B		
C	12	A	CAB	N	B	C	

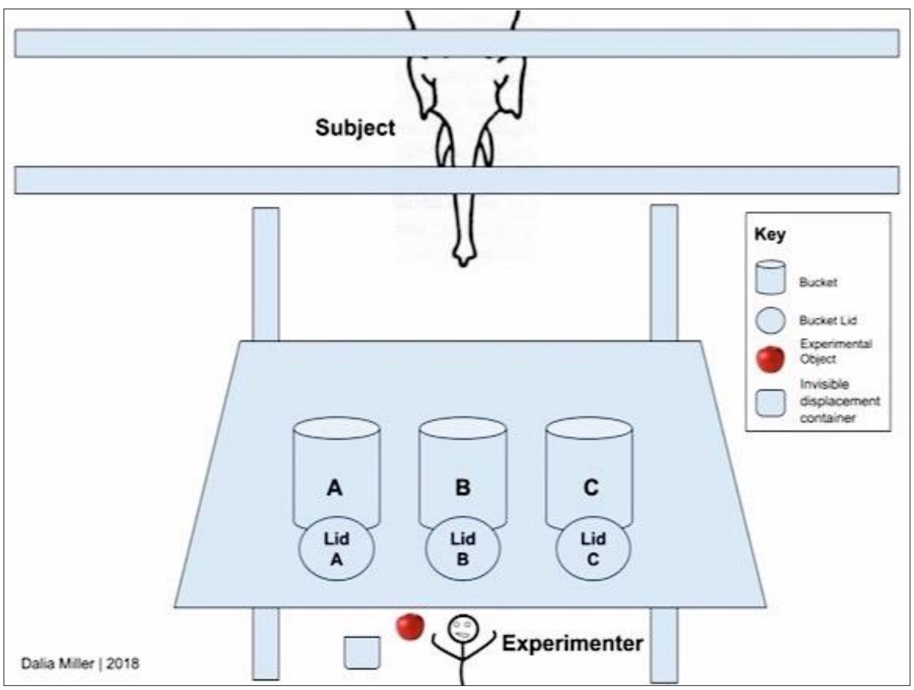
Apples were designated as the target displacement object (i.e., food reward) in test and control trials. When a subject failed, successive bucket searches were prevented by quickly retracting the apparatus beyond reach so a subject was not able to access the reward in another bucket. Subjects appearing to demonstrate less taste preference for apples were tested with a ~10 cm length of sugarcane when an apple did not appear to retain a subjects’ interest in a test session.

Materials

The test site consisted of two distinct areas, one for the subject and one for the experimenter. The site was partitioned with aluminum pipes secured through concrete support pillars. The lower pipe was 162.56 cm from the ground and the upper 46.99 cm above the lower pipe. This site was regularly used for elephant cognition research, and was built in 2011.

Figure 2

Depiction of the experiment test site, apparatus, and materials with subject and experimenter shown in their designated trial outset positions.



The apparatus consisted of a 121.92 by 121.92 cm plywood board on the ground. White chalk markings ensured the placement of the apparatus remained consistent. Two 121.92 cm long, 5.08 cm wide redwood segments were secured on top of the board, parallel to the left and right lengths, 10.16 cm inward from the lengthwise edges. The segments bracketed a vertical path used to maneuver the apparatus into the subjects' trunk range.

A redwood plank measuring 91.44 cm long and 22.86 cm wide was secured under three opaque plastic, 19-litre buckets, as shown in Figure 3. Two steel bolts were drilled lengthwise through the bottom of each bucket into the redwood plank. During a test, the experimenter stood behind the center bucket, bucket B. Bucket A was located on the experimenter's left and bucket C on the experimenter's right. The left outside edge of bucket A was 10.16 cm from the left plank edge and the right outside edge of bucket C was affixed 10.16 cm from the right edge of the plank. 46.99 cm separated the interior edge of bucket A from bucket B and 46.99 cm separated the interior edge of bucket C from bucket B.

Figure 3. Photograph of the experiment apparatus described in the Materials section.

Three-bucket lids each measured a 135 cm circumference. Lids were placed against buckets at a vertical angle during testing, as shown in Figure 4. Prior to a subject choice phase, lids were placed on buckets upside down allowing subjects to easily remove a lid and indicate a bucket choice.

Figure 4. Photograph detailing apparatus with sponges lining the buckets. Lids are depicted in the vertical test position. An object (i.e. reward) is in bucket C.

Yellow kitchen sponges were arranged inside the buckets to cover the bottom of each bucket, as shown in Figure 4. The sponges muted any sound of contact between the apple and bucket during a displacement, and held the apple in a secure position when the apparatus was moved up to the subject in a choice phase. When a subject removed sponges from a bucket in a choice phase, the sponges were replaced before resuming the session. Sponges were changed between subjects, and were cleaned daily with water.

Two blue plastic PVC pipes, 14 cm in size and 106 cm in length, were secured lengthwise underneath the redwood plank, one 7.62 cm from the left plank edge and one 7.62 cm from the right plank edge, as shown in Figure 3 and Figure 4. The pipes functioned as handles for the apparatus. Each pipe was secured to the plank with two aluminum pipe clips bolted to the underside of the platform. Four aluminum pipe clips and eight bolts were used in total. When clips became loose during a session, dry bamboo secured gaps between the pipe and the clips.

A 3-liter bucket held the apples behind the experimenter so that each trial could be easily reset. A 121-liter plastic garbage can stored sunflower seeds in the rear, right corner of the test site during test sessions but was always out of experimenter and subject reach. A .24-liter plastic pail stored in the garbage can was used to scoop the seeds. Seeds provided a different form of positive reinforcement when subject attention dwindled or when a subject was frustrated.

A 1-liter opaque green plastic container was used in invisible displacement tasks 4, 5 and 6 to conceal an object in test trials. A container lid was created using opaque black corrugated plastic and precisely covered the container opening, measuring a 15.71 cm circumference.

Materials were stored in a locked corrugated metal shed adjoining the test site. A camcorder attached to a tripod was positioned in front of the storage shed doors, outside of the experimental area. All sessions were recorded and a small digital camera was used to take photographs. The experimenter wore sunglasses throughout each test session to eliminate gaze-related cues. Bucket lids controlled for olfaction and sponges controlled for the sound of apple and bucket contact. Sponges also stabilized the apples in position so when the apparatus was moved, the apple did not move or make contact with the interior walls of a bucket. When daily testing was concluded, sponges, buckets, and lids were cleaned. In a control trial, an opaque grey foam mat blocked a subject's view of an experimenter, trial procedures, and apparatus. The control mat measured .45 cm thick, 259.08 cm length, and 138.43 cm width.

Mahouts were responsible for bringing their elephant to the test site. An experimenter conducted testing with the support of at least one data assistant and at least one or two control assistants. A data assistant sat on an upside-down garbage can beside the storage shed, near bucket A. The data assistant announced each pre-assigned bucket displacement and lid order placement for an experimenter and recorded each trial bucket selected. At the end of a test session, correct choices were reviewed together by experimenter and data assistant, noting criterion and, accordingly, whether the elephant could be advanced to the next task. A data assistant also monitored subject attention in control trials advising when necessary to restart a control trial due to a distracted subject.

A control assistant was responsible for the control mat. During test trials, this assistant stood on the ramp to enter the experiment area. When a data assistant announced a control trial, a control assistant entered the site holding the mat between experimenter and subject as a visual barrier prior to the choice phase. During test trials, this assistant took photos and provided sunflower seeds to a subject at the request of an experimenter.

Pre-trial training was used to familiarize subjects with the apparatus, the basic concept of an object search, and the process of lid removal. Table 3 details the pre-trial training phases.

Table 3

Three pre-trial training phases, detailing the number of searchable buckets, lid use, number of times phase administered to a subject, object inclusion, and end of training.

Phase	No. Buckets Searchable	Lids (Y/N)	Administered	Notes
1	3	N	Once	Without object
2	3	Y	Once	With object
3	1	Y	Flexible	With object, training ends after two consecutive correct choices

A test trial started by first establishing a subject's interest and visual attention. Calling a subject by name, an experimenter stood behind bucket B and extended their right hand holding an apple. Subject trunk extension toward the object confirmed interest and attention to the experimenter. A test session officially commenced when a data assistant announced an assigned bucket location for the first object displacement according to information from the data sheet. Table 4 provides details about each task and associated experimental procedures.

Table 4

Basic task information.

Task Order	Task	Paradigm	Object Displacement/s
1	Single Visible Displacement (SVD)	Visible	1 (Single)
2	Double Visible Displacement (DVD)	Visible	2 (Double)
3	Triple Visible Displacement (TVD)	Visible	3 (Triple)
4	Single Invisible Displacement (SID)	Invisible	1 (Single)
5	Double Invisible Displacement (DID)	Invisible	2 (Double)
6	Triple Invisible Displacement (TID)	Invisible	3 (Triple)

Task order was established according to Piaget's theory of object permanence, with lesser cognitive demands represented by visible displacement tasks and advanced cognitive demands represented by invisible displacement tasks (Piaget & Cook, 1952). Tasks 1 - 3 examine object permanence according to Piaget's stage 5, with the number of object displacements increasing according to task succession (single, double, and triple displacement). Stage 6 object permanence is examined in tasks 4, 5, and 6; these tasks were also administered in order of increasing number of object displacements.

Randomization Protocols

Each test session included a number of randomization procedures to control for possible "Clever Hans" cueing. Data sheets included randomly assigned buckets in each trial displacement and a randomized order of lid placement on the buckets to curb subjects possibly developing an association between a choice and the last bucket where a lid was placed. As shown in Table 5, a test session consisted of 12 trials with eight tests and four controls. Each session began with three successive tests and the remaining five tests and four control trials were interspersed pseudo-randomly. This randomization procedure ensured subjects would not be able to predict when a control trial would occur.

Table 5

Test session procedures applied in each task.

Task		Task Test Sessions		Trials		
Order	Type	Minimum	Maximum	Tests	Controls	Total
1	SVD	2	10	8	4	12
2	DVD	2	10	8	4	12
3	TVD	2	10	8	4	12
4	SID	2	10	8	4	12
5	DID	2	10	8	4	12
6	TID	2	10	8	4	12

The criterion for subjects to advance according to the successive task order used a significant binomial test as a measure of success. This criterion for success to advance tasks was based on a combined subject score in two consecutive test sessions, consisting of 10 (or more) test trials correct among 16 test trials. As shown in Table 5, each task was allotted a maximum of 10 test sessions. In visible displacement task 1 (SVD) and task 2 (DVD), performance failing to meet criterion resulted in ceasing visible displacement tests. Subjects then skipped any remaining visible displacement tasks, and advanced directly to the first task of invisible displacement, task 4 (SID). Subjects failing to succeed according to criterion in an invisible displacement task, however, still completed testing in invisible displacement task 4, task 5, and task 6. Relevant literature about elephant perception suggests that vision may be secondary to other senses in the decision-making process, but research examining vision directly in its application to problem-solving has been limited. Accordingly, this methodology provided that all invisible displacement tasks were administered across subjects to develop an understanding of the elephants' capacity to solve problems using incomplete, abstract visual information.

Task 1: Single Visible Displacement (SVD)

A data assistant announced the trial bucket assignment on the data sheet, followed by the lid placement order. An experimenter stood behind bucket B, and stepped sideways, left or right if an object displacement was in bucket A or bucket C. An experimenter remained in place behind bucket B if bucket B was announced. A subject observed as an experimenter then displaced an object in an assigned bucket. An experimenter returned (if necessary) to their initial bucket B position, then placed lids on all buckets according to the lid placement order. Finally, for the choice phase, an experimenter pushed the apparatus into trunk reach of the subject. Using their trunk, a subject made contact with a bucket or removed a bucket lid. The first bucket contacted by a subject was recorded as the trial choice.

Task 2: Double Visible Displacement (DVD)

A data assistant announced an order of two buckets according to a data sheet with an experimenter standing behind bucket B. An experimenter stepped behind the first of the two buckets announced and displaced the food reward in the bucket. After a brief pause, an experimenter removed the food from the bucket, stepped behind the bucket designated for the next successive displacement, and displaced it in the bucket. An experimenter returned to position (if necessary) behind bucket B. A data assistant then announced the order of lid placements, and an experimenter placed lids on the buckets and maneuvered the apparatus into the choice phase position. A correct choice in task 2 was the second and last bucket where an object was displaced.

Task 3: Triple Visible Displacement (TVD)

Task 3 followed task 2 experiment procedures, with the addition of a third successive object displacement. Accordingly, a data assistant announced an order of three bucket displacement assignments, and an experimenter successively displaced an object between the three buckets in the order assigned. A correct choice in task 3 was the third and last bucket where an object was displaced.

Task 4: Single Invisible Displacement (SID)

A data assistant announced a bucket assignment according to a data sheet, followed by the lid placement order. Behind bucket B an experimenter held the invisible displacement container and lid in their left hand and an object in their right hand. An object was then placed inside the displacement container, and a lid was placed on the container. Holding the container with both hands, an experimenter stepped to, or remained behind, the assigned displacement bucket. An experimenter flipped the container, so the lid was on the bottom and lowered the container into the bucket. Resting on the bucket sponges, removal of the container lid released an object into the bucket. Holding the container in their right hand, and lid in left hand, an experimenter returned to position (if necessary) behind bucket B. An experimenter then showed the subject the open and empty container and then placed the container and lid behind the testing apparatus on the ground. A data assistant announced the order of lid placements, and then an experimenter placed lids on the buckets accordingly and maneuvered the apparatus into the choice phase position. A subject made contact with a bucket or removed a bucket lid, indicating a choice. The correct choice was the only bucket visited by the displacement container.

Task 5: Double Invisible Displacement (DID)

Task 5 applied the invisible displacement procedures outlined in task 4, with the addition of a second successive invisible object displacement. When an experimenter lowered the container into the first displacement bucket, the experimenter did not remove the container lid. After a brief pause, an experimenter lifted the container out of the bucket, and stepped behind the second designated displacement bucket. The container was again lowered into the bucket, and this time, an object was released from the container. Holding the container in their right hand, and lid in the left hand, an experimenter returned to position (if necessary) behind bucket B. An experimenter then showed the subject the open and empty container to the subject, and then placed the container and lid behind the testing apparatus on the ground. A data assistant announced the order of lid placements, and an experimenter placed lids on the buckets accordingly and maneuvered the apparatus into the choice phase position. A subject made contact with a bucket or removed a bucket lid, indicating a choice. The correct choice was the second and final bucket the displacement container visited.

Task 6: Triple Invisible Displacement (TID)

Task 6 applied the invisible displacement procedures outlined in tasks 4 and 5, with the addition of a third successive invisible object displacement. When an experimenter lowered the container into the first displacement bucket, the experimenter did not remove the container lid. After a brief pause, an experimenter lifted the container out of the bucket, and stepped behind the second designated displacement bucket and again lowered the container into the bucket. Pausing again, the experimenter lifted the container and stepped behind the third displacement bucket. The container was lowered into the bucket and an object was released into the bucket. Holding the container in their right hand, and lid in the left hand, an experimenter returned to position (if necessary) behind bucket B. An experimenter then showed the subject the open and empty container to the subject, and then placed the container and lid behind the testing apparatus on the ground. A data assistant announced the order of lid placements and an experimenter then placed lids on the buckets accordingly and maneuvered the apparatus into the choice phase position. A subject made contact with a bucket or removed a bucket lid, indicating a choice. The correct choice was the third and final bucket the displacement container visited.

Bias elimination training

When a subject demonstrated avoidance of the same single bucket in two consecutive test sessions, a subject was administered bias elimination training during a pause in testing. Bias elimination training reintroduced the avoided bucket to a subject through positive reinforcement. First, without lids, an object was displaced repeatedly in the avoided bucket, and a subject was able to search all buckets during the choice phase. Once a subject correctly chose the avoided bucket first in two consecutive trials, lids were introduced. In this second phase, an experimenter continued single object displacement using only the avoided bucket. The protocol considered the bucket bias eliminated when a subject demonstrated two consecutive correct bucket choices in the second training phase. A subject subsequently resumed testing according to the task and session last administered.

Inattentive or frustrated subjects were provided 240 mL of sunflower seeds to regain interest or to calm a subject. Most frequently, seeds were introduced between test sessions, although, they were occasionally provided if subject behavior suggested that a test session might require premature termination.

Data Analysis

Due to the small sample size, statistical analyses were performed with non-parametric tests. Because there were three buckets in each trial and thus three choices, the chance probability of subject success in one trial was $p = .33$. All analyses were performed using a .05 alpha level of significance. Subject performance was analyzed using several tests, including, Wilcoxon signed-rank exact tests to compare test trial success to chance and to compare control trial success to chance. Linear regression analyses examined subject performance across tasks to explore a possible predictive relationship between task type and success. Significant differences between the tasks were evaluated with a Friedman test. Spearman Coefficient of Rank calculations examined the relationship between task order and performance. Specifically, the Spearman analyses examined the correlation strength between subject performance and each of two proposed task orders offering distinct task rankings according to different hierarchies of demand.

Results

Six subjects participated in tasks 1, 2, 4, 5, and 6. Two subjects, Beau and Dah, skipped task 3 after failing to meet criterion in task 2. Beau and Dah advanced directly to task 4. Across tasks, test session 1 performance provided a measure of success when a task was unfamiliar, before task learning could occur. A two-tailed Wilcoxon signed-rank exact test compared subject performance in test session 1 (8 test trials per test session) of each task. Success was compared to the chance value 2.6667. The Wilcoxon analyses showed success was significantly greater than chance expectations in task 1, ($W = 21$, $p = .0277$), in task 4, ($W = 21$, $p = .0277$), and in task 6, ($W = 21$, $p = .0277$).

In each task, a 'standard of success' was defined as the fewest number of test sessions in which any one elephant reached criterion. Across tasks, the total number of correct test trials a subject scored in test sessions encompassed by a task specific 'standard of success' were applied to examine subject performance. Table 6 provides the number of test sessions per task a subject completed, and, if relevant, indicates subject failure to meet a task criterion. Tasks 1, 3, 4, and 5, provided a two-test session 'standard of success.' Subject success was examined against a chance value of 5.3333 test trials correct (i.e., 16 total test trials / 3 choices per trial). Tasks 2 and 6 provided a three-test session 'standard of success' and subject success was examined against a chance value of 8 test trials correct (i.e., 24 total test trials / 3 choices per trial).

Table 6

The number of test sessions a subject completed in each task. Tasks 1-3 are visible displacements and tasks 4-6 are invisible displacements.

Subjects	Task 1[a]	Task 2[a]	Task 3[b]	Task 4[a]	Task 5[a]	Task 6[a]
Beau	3	10*	-	10	10*	10*
Dah	4	10*	-	7	10	3
Lanna	4	3	2	5	10*	9
Pluem	3	4	6	2	5	10*
Prae	2	4	5	7	4	10*
Yui	2	10	5	2	2	10*

Note. *Criterion not met.
[a]$n = 6$. [b]$n = 4$.

In task 1, Prae and Yui set a two-test session 'standard of success.' Calculating the total number of correct test trials performed in task 1 by each elephant (based on 16 total test trials in test sessions 1 and 2), a two-tailed Wilcoxon signed-rank exact test found the elephants chose the correct bucket significantly more often than chance, ($W = 21$, $p = .0277$). In task 2, Lanna set a three-test session 'standard of success.' Calculating the total number of correct test trials performed in task 2 by each elephant (based on 24 total test trials in test sessions 1, 2, and 3), a two-tailed Wilcoxon signed-rank exact test found the elephants did not choose the correct bucket significantly more often than chance expectations, ($W = 19$, $p = .0747$). In task 3, Lanna set a two-test session 'standard of success.' Calculating the total number of correct test trials performed by four subjects (based on 16 total test trials in test sessions 1 and 2), a two-tailed Wilcoxon signed-rank exact test found the elephants did not choose the correct bucket significantly more often than chance expectations, ($W = 10$, $p = .0679$). In task 4, Pluem and Yui set a two-test session 'standard of success.' Calculating the total number of correct test trials performed by each elephant (based on 16 total test trials in test sessions 1 and 2), a two-tailed Wilcoxon signed-rank exact test found the elephants chose the correct bucket significantly more often than chance, ($W = 20$, $p = .0464$). In task 5, Yui set a two-test session 'standard of success.' Calculating the total number of correct test trials performed by each elephant (based on 16 total test trials in test sessions 1 and 2), a two-tailed Wilcoxon signed-rank exact test found the elephants did not choose the correct bucket significantly more often than chance expectations, ($W = 16$, $p = .2489$). In task 6, Dah set a two-test session 'standard of success.' Calculating the total number of correct test trials performed by each elephant (based on 24 total test trials in test sessions 1, 2, and 3), a two-tailed Wilcoxon signed-rank exact test found the elephants chose the correct bucket significantly more often than chance, (W = 15, p = .0431). Corresponding data and results are reported in Table 7.

Table 7

Correct test trials based on a task 'standard of success.' Wilcoxon signed-rank W and p values are reported by task.

Subjects	Task 1[a]<>	Task 2[a]◆	Task 3[b]<>	Task 4[a]<>	Task 5[a]<>	Task 6[a]◆
Beau	8	13	-	7	2	8
Dah	7	13	-	8	5	15
Lanna	7	12	11	5	6	11
Pluem	9	12	8	10	9	11
Prae	10	10	6	7	6	11
Yui	10	5	8	16	11	13
α = .05	W = 21, p = .0277	W = 19, p = .0747	W = 10, p = .0679	W = 20, p = .0464	W = 16, p = .2489	W = 15, p = .0431

Note. <>Denotes chance = 5.3333; ◆Denotes chance = 8.
[a]n = 6. [b]n = 4.

To examine subject performance across tasks, linear regression analyses were applied to subject data from all test sessions. The regressions examined relationships between task and performance (all correct test trials in all test sessions) as shown in Table 8. Figure 5 graphs a best fitting line for each subject according to the linear regression analyses. Each graph's x-axis corresponds to a task number and each graph's y-axis represents the correct number of test trials achieved in a test session. The data points are plotted according to the successful test trials scored in a single test session.

Table 8

Subject linear regression performance analyses.

Subject	Equation	r^2	Significance
Beau	y = - 0.412x + 4.795	.257	F(1, 41) = 14.16, *p* = .0005*
Dah	y = 0.0663x + 3.77	.01	F(1, 32) = 0.34, *p* = .5647
Lanna	y = - 0.195x + 4.62	.015	F(1, 30) = 0.30, *p* = .5854
Pluem	y = - 0.248x + 5.14	.091	F(1, 28) = 2.80, *p* = .1055
Prae	y = - 0.195x + 4.62	.057	F(1, 30) = 1.82, *p* = .1875
Yui	y = 0.034x + 4.26	.001	F(1, 29) = 0.04, *p* = .8506

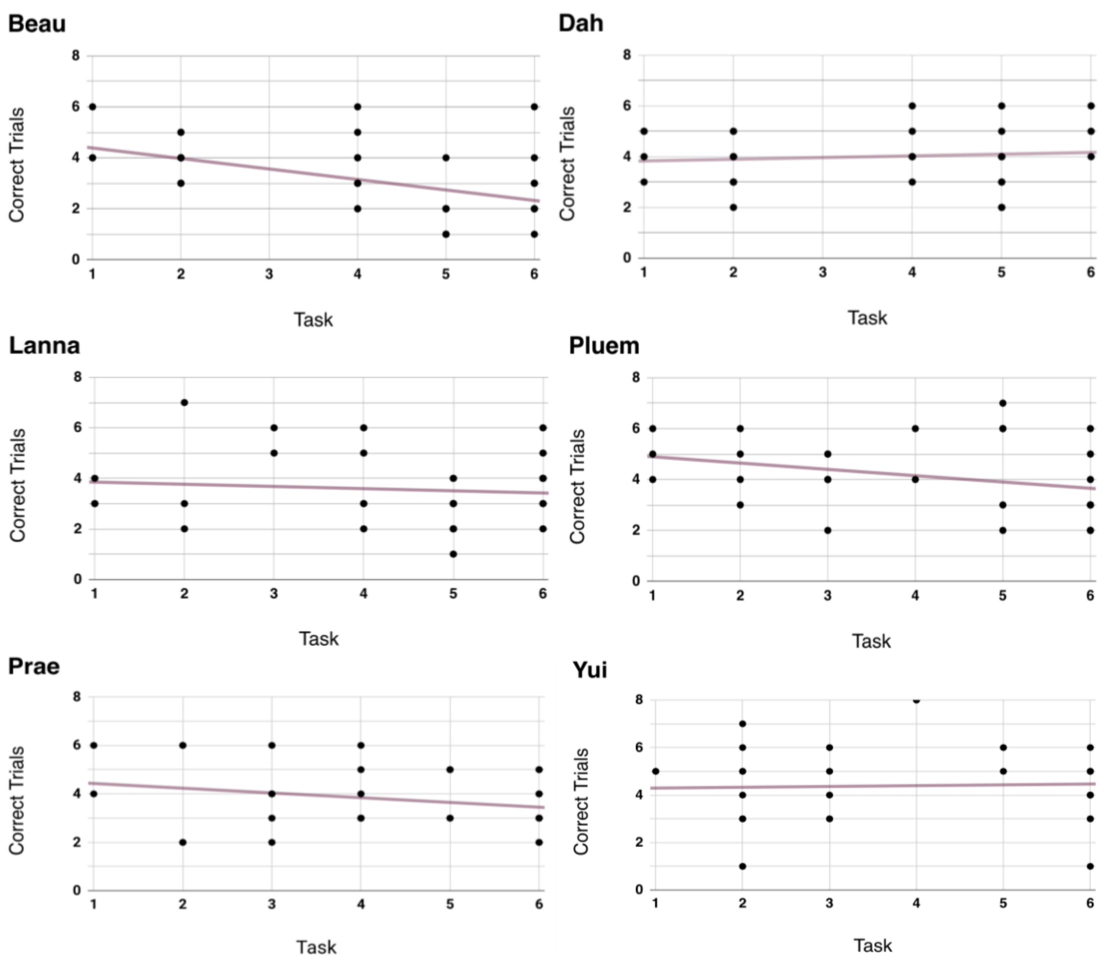
Note. *$p < .01$

The regressions found one significant result, shown in Table 8. A coefficient of determination of .257 indicates a medium effect size and that 25.7% of performance is explained by task type. Beau's results demonstrate a significant relationship between task type and performance, [F(1, 41) = 14.16, *p* = .0005]. The slope coefficient for task type, - 0.412, demonstrates Beau's success decreased by 0.412 in each successive task.

Four subjects demonstrated a negative relationship between task type and success (with Beau being the only elephant with a statistically significant result), with success decreasing across tasks. Two subjects exhibited a positive relationship between task and success showing small improvements in performance as tasks advanced.

Figure 5

Subject linear regression graphs with each best fitting line graphed according to correct test trials a subject performed in a task.



Because subjects advanced through tasks at varying rates, to further assess performance across subjects, the number of successful test trials achieved by an elephant in a given task was divided by the total number of sessions the elephant completed in that task. Table 6 shows the number of test sessions a subject completed in each task, and Table 9 provides proportional subject performance scores and the corresponding task mean values.

Table 9

Subject performance in proportion of total number of correct test trials divided by total number of test sessions administered in a task. Mean task performance is included.

Subject	Task 1[a]	Task 2[a]	Task 3[b]	Task 4[a]	Task 5[a]	Task 6[a]
Beau	6.00	3.90	-	4.00	1.90	2.80
Dah	4.25	3.70	-	4.29	3.70	5.00
Lanna	4.50	4.00	4.00	3.80	2.70	3.89
Pluem	5.00	4.50	4.00	5.00	4.80	3.30
Prae	5.00	4.00	3.80	3.86	4.00	3.20
Yui	5.00	3.80	4.20	8.00	5.50	4.00
M	4.96	3.98	4.00	4.83	3.77	3.70

Note. [a]$n = 6$. [b]$n = 4$.

Means were used to rank tasks according to success, from high to low; higher success was designated with a lower number for difficulty rank (1 – 6). Tasks are listed according to this order in Table 10.

Table 10

Rank order of tasks according to mean group success in each task based on the proportion of total number of correct test trials to total number of test sessions in each task from Table 9. Tasks were ranked from highest success (1) to lowest success (6).

Task	Rank	Mean Success
1[a]	1	4.96
4[a]	2	4.83
3[b]	3	4.00
2[a]	4	3.98
5[a]	5	3.77
6[a]	6	3.70

Note. [a]$n = 6$. [b]$n = 4$.

To evaluate differences in success across tasks, a Friedman test compared tasks 1, 2, 4, 5, and 6. Task 3 was excluded due to a low, unequal subject number. Initial task ranks were obtained using the normalized subject performance scores provided in Table 9. A Friedman test found no significant differences between the five task treatments, $\chi^2_r = 7.30$ (df = 4, $n = 6$), $p > .05$. The results are reported in Table 11.

Table 11

The ranked order of tasks provided by Friedman test results. Task rankings reflect most to least success according to subject performance in each task.

Task	Avg. Rank	Sum of Ranks
1	4.25	25.50
4	3.58	15.00
2	2.50	21.50
5	2.33	14.00
6	2.33	14.00

Note. $p = .1209$.

To examine whether task order appropriately represented task demands, Spearman Coefficient of Rank calculations measured correlations between subject success and the task order administered. To examine a post hoc hypothesis representing a different prediction about task demands, correlations were calculated according to a task order presented by increasing sequential number of object displacements.

Table 12 provides the results of each two-tailed analysis with the correlation values for each hypothesis presented side by side to compare the strength of each correlation between subject performance and a task order. The significant critical values noted in Table 12 correspond to subject task participation. Beau and Dah were assigned a critical value accounting for non-participation in task 3. Results were corrected for ties.

Table 12

Calculated by subject, the Spearman Coefficient of Rank Correlation results measure the correlations between task order and subject performance, according to two distinct task demand hypotheses.

	r_s	
Subject	Order Tested	Order Post Hoc
Beau◆	+ .800	**+ .900**
Dah◆	+ .410	+ .154
Lanna<>	**+ .812**	+ .319
Pluem<>	+ .464	**+ .928**
Prae<>	+ .696	**+ .812**
Yui<>	- .143	+ .429

Note. <>Denotes a ± .811 critical value. ◆Denotes a ± .878 critical value. Boldface r_s values are significant.

These results show Lanna's performance is significantly correlated with the tested task order, according to an obtained r_s = + .812, exceeding the corresponding ± .811 critical value. Three results were significantly correlated to the re-ordered task hypothesis; with an r_s = +. 900, Beau exceeded the corresponding ± .878 critical value. Pluem, demonstrated an r_s = + .928, and Prae, an r_s = + .812, respectively, and thus the two r_s values exceeded the corresponding ± .811 critical value. Dah and Yui reported non-significant r_s results according to each task order examined.

Discussion

The elephants' performance during this study supports the initial study predictions that: a) elephants have object permanence concordant with Piaget's stage 5, b) elephants can apply vision to succeed in object permanence tasks, and c) elephants possess the cognitive skills to solve object permanence tasks. Broadly, the results of this study support the suggestion that Asian elephants possess object permanence.

To move to the next task, a subject's performance was assessed based on whether they reached criterion of 10 correct test trials within two consecutive test sessions. This was based on a significant binomial (10/16 test trials, $p < .05$), but the statistical analyses performed to assess overall success were not based on this criterion. Rather, successful performance was examined in direct comparison to chance predictions of success according to a specified analysis.

Performance in the first test session was significantly better than chance in task 1, task 4, and task 6, demonstrating the elephants succeeded when tasks were novel. It is possible this result demonstrates task familiarity and knowledge of specific task expectations were not pre-conditions for success. However, it is also possible this result demonstrates that increasing familiarity with general expectations and basic test procedures enhanced success in later tasks, presumed more difficult. Test session 1 success might demonstrate mental flexibility in elephants, if, as it appears, they applied an approach to problem solving which was adapted according to each new set of unique task procedures.

Performance was also examined according to a 'standard of success' in each task, established according to the quickest advancing subject/s. In each task, the earliest test session in which a subject reached criterion was extrapolated to provide expectations for the group. An analysis of the data representing the standard of success across tasks provided a way to examine whether subject performance was consistent with the expectations established by the highest performer. Across tasks, standards of success were consistently established early, following test session 2 or test session 3. The standard bearers of these expectations were diverse; five subjects achieved scores attributed to these standards of success.

Based on this standard of success, the elephants performed significantly better than chance in task 1, task 4, and task 6. Notably, tasks 1 and 4 were each single displacements and tasks 4 and 6 were single and triple invisible displacements, respectively. These findings might show subjects interpreted single displacement tasks as least demanding. Most unexpected was the fact that elephants performed significantly better than chance in two invisible displacement tasks, as these tasks were presumed to require higher cognitive demands than invisible displacement tasks. Specifically, the cognitive demands presented in task 6 were based on both the invisible task paradigm and triple object displacement. It is possible that administering tasks in succession according to the Piagetian model reinforced the elephant's understanding of higher demands, as advanced concepts were presented in different iterations. According to this interpretation of the results, perhaps the advantage of experience facilitated success in task 6. Nonetheless, together, the results demonstrate elephants succeed in Piaget's stage 5 and stage 6, and show basic and advanced object permanence.

A wider analysis of subject performance was conducted using linear regressions to analyze the total success achieved by each subject across tasks. These analyses were performed according to an assumption that task type (i.e., increasing task number) and success approximated a linear relationship. Challenging this assumption, five subjects did not exhibit a significant predictive relationship between task type and success. On the surface, these findings appear to show that increasing task demands did not diminish success. Interpreted differently, the results may support the interpretation of test session 1 performance suggesting success was enhanced by a generalized learning effect. If so, the results of the linear regressions suggest that with experience, the capacity for success expands, counterbalancing increasing demands. This perspective might explain why the regression results were significant for only one subject, Beau, who demonstrated less success as tasks advanced. It is however notable that Beau participated in one fewer tasks than most subjects, failing to meet criterion in task 2 and skipping task 3.

Having assumed a linear relationship between task type and success, the linear regression results were unexpected. Based on these unexpected findings, this study examined whether there were possible differences between the tasks that the linear regressions failed to detect. Task differences were analyzed with a Friedman test, and the results did not indicate significant differences between task treatments. The Friedman test did, however, provide a new ranked task order reflecting task performance (excluding task 3) that was used to develop a hypothesis for a new rank order of difficulty for tasks. This ranking didn't reflect the same task order presented in this experiment, but it did demonstrate performance was highest in tasks 1 and 4. This interpretation of task success is consistent with the results obtained in the analyses of task standards of success, which found performance was significantly above chance in tasks 1 and 4.

These results were interpreted as a potential challenge to task difficulty assumptions. According to Piaget, object permanence task demands are defined primarily according to whether a task is a visible displacement (stage 5) or an invisible displacement (stage 6) (Piaget & Cook, 1952). Secondary to this demand is the number of object displacements presented in a task.

Because elephant performance did not appear to be consistent with this proposed hierarchy of task demands, performance was examined according to a post hoc task demand hypothesis. This alternative hypothesis predicted the opposite order of primary and secondary demands, or that a successive increase in the number of object displacements was primary over whether the task was a visible displacement or invisible displacement. The purpose of this post hoc hypothesis was to explore the possibility that, for elephants, the increasing task order presented in this study and based on Piaget's successive ordering of tasks 1 - 6 is not necessarily synonymous with increasing difficulty or cognitive demand.

To test the strength of each hypothesis (1: tasks 1-6 were presented in order of increasing difficulty, 2: tasks 1-6 represented a different order of difficulty for elephants), Spearman correlations were run to examine performance according to the task order administered and according to the post hoc hypothesized task order. The results found three subjects demonstrated performance significantly correlated to the post hoc hypothesis, while one subject demonstrated performance significantly correlated to the task order administered. Two subjects did not show a significant correlation between performance and either task order tested. According to these results, the elephant perspective might be better understood according to the post hoc task demand hypothesis.

The criterion used to define when to advance elephants through the tasks resulted in unequal test sessions administered across subjects and tasks and revealed considerable variability among elephants for the number of sessions completed. Thus, subject data were normalized as a proportion by task, dividing the total number of correct test trials by the total number of test sessions administered to each elephant. These calculated values allowed for direct performance comparisons across elephants, as well as a measurement of mean task performance.

The normalized subject scores demonstrated that there was indeed variability in performance between individuals. Yui achieved the highest score across tasks (8 trials correct) in task 4 and Beau demonstrated the lowest overall score (1.9 trials correct) in task 5. One possible explanation for performance variability may be attributed to individual differences. During testing, differences between subjects were anecdotally observed in the areas of attention, interest, engagement, motivation, and general mood. While subject memory may also have differed between individuals, it was not directly examined.

Variability in subject attention may have been the result of unequal motivation to solve tasks. Taste preferences may have provided varying preferences for apples. It is also possible that at the beginning of the experiment, apples provided a degree of positive reinforcement that declined over the course of the four months of testing. Accordingly, it is possible that, for some subjects, the quality of the reward decreased over time.

To examine the elephant's use of vision in object permanence, this study's methodology controlled for all non-visual cues. An analysis of control trial performance was one measure used to examine if elephants could use vision alone to succeed in experimental trials. This analysis examined whether subjects were able to succeed above chance when visual cues were blocked, and the results showed the elephants were not able to do so. This result may suggest the elephants were guessing when visual information was inaccessible. Extending this interpretation to examine success in test trials, it is possible success was contingent on the capacity to process observed information accurately and apply that information to make choices and was obtainable only if elephants attended to visual cues and then recalled a sequence of visual information to make a choice. Because the elephants were unable to find the food in control trials, it seems unlikely that the elephants were using either acoustic or olfactory information to locate the food in experimental trials.

While the Piagetian task order is widely supported in object permanence literature, findings in this study appear to suggest that the elephants did not perceive the tasks according to the task order administered. This suggestion is supported by the results obtained by comparing mean task performance across individuals using the Friedman test, mean subject performance across tasks, and performance according to all task standards of success. It is possible that elephants were challenged by the increasing duration of the procedures provided by multiple object displacements. It is also possible that the sustained visual attention required to observe a moving object or container presented heightened challenges when sequences of movement were lengthier and more complex. It is possible that the visual concentration needed to process long sequences might present a specific unique set of challenges to elephants.

While elephants appear to demonstrate use of vision to succeed in object permanence tasks, this sample was small and thus more research is needed to better understand individual differences between elephants. Although this study examined object permanence in captive elephants, it is possible that wild elephants possess similar capacities, as the literature suggests captive and wild elephants demonstrate similar behavioral adaptations (Schulte, 2000). However, it would be difficult to conduct a controlled object permanence experiment with wild elephants.

This study contributes to a broader understanding of elephant cognition and sensory processing, and has direct implications for conservation in practice. Species survival will be determined by current conservation efforts. Enhanced understanding of elephant cognition offers conservationists the means to design better strategies to protect elephants.

Future Research

Success in invisible displacement tasks warrants deeper examination in future studies. One way to examine this finding might be to administer invisible displacement tasks before visible displacement tasks. As the Spearman correlations show, the number of object displacements might be more salient or relevant to elephants than the visible or invisible paradigm applied to a task. Altering task order in accordance with the post hoc hypothesized task order might present a new way to understand more about task demands (De Blois et al., 1998). This reversal of visible and invisible displacement task order has been applied to object permanence research conducted with other species, including cats (Doré, 1986). Future research might also examine invisible displacement using a between subjects design to determine if significant differences emerge between tasks when each group is tested in a single task condition.

Future studies might also examine the ontogeny of object permanence in elephants, and explore whether the capacity emerges in distinct developmental stages. However, because Asian elephants are endangered and give birth to a single calf after a 22-month gestation period, it would be difficult to access and test juvenile elephants of differing ages (Schulte, 2000).

Another avenue for future research would be to replicate this study with male elephants. Male and female elephants in the wild develop certain distinct adaptations resulting from social and temperamental differences (Schulte, 2000). Examined together with the results of this study, male performance in object permanence tasks might offer a broader understanding of divergent behavioral adaptations presented in a problem-solving context.

This experiment found elephants demonstrated a capacity for solving object permanence tasks, affirming this study's predictions. As a testament to their intelligence, elephants demonstrated consistent comprehension of object permanence concepts. The elephants' success in invisible displacement tasks supports the notion that they possess complex cognitive skills that may relate to mental representation and abstract thinking.

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