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Initial Findings on Visual Acuity Thresholds in an African Elephant (*Loxodonta africana*)

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Abstract

There are only a few published examinations of elephant visual acuity. All involved Asian elephants (*Elephas maximus*) and found visual acuity to be between 8' and 11' of arc for a stimulus near the tip of the trunk, equivalent to a 0.50 cm gap, at a distance of about 2 m from the eyes. We predicted that African elephants (*Loxodonta africana*) would have similarly high visual acuity, necessary to facilitate eye-trunk coordination for feeding, drinking and social interactions. When tested on a discrimination task using Landolt-C stimuli, one African elephant cow demonstrated a visual acuity of 48' of arc. This represents the ability to discriminate a gap as small as 2.75 cm in a stimulus 196 cm from the eye. This single-subject study provides a preliminary estimate of the visual acuity of African elephants.

Introduction

Studies of elephant sensory systems have emphasized hearing [Heffner and Heffner, 1982; Langbauer, 2000; Poole et al., 1988; Wood et al., 2005], smelling [Rasmussen, 1998], and, more recently, seismic communication [O'Connell-Rodwell et al., 2006]. There have been surprisingly few studies of vision in elephants [Daniel, 1999; Nissani et al., 2005; Rensch, 1957] and only one study of visual acuity in (Asian) elephants [Bennett, 1987].

Most anatomical/topographical studies of the retina have examined Asian elephants [Murphy et al., 1992], although Yokoyama et al. [2005] showed that both Asian and African elephants share visual pigments with human color-blind deuteranopes. Stone and Halasz [1989], studying the eye of a stillborn African elephant calf, found the usual pattern of ganglion cells concentrated on a horizontal axis across the retina below the optic disc. They also found a unique pattern: ganglion cells concentrated in the upper temporal retina, and speculated that this extra concentration would allow visual monitoring of the trunk. The most thorough study of elephant brain structure [Shoshani et al., 2006] indicates that the occipital lobe is relatively underdeveloped compared to the olfactory lobes and the temporal lobes, consistent with an interpretation that, for elephants, hearing and smell are much more elaborate senses than vision.

We tested binocular visual acuity in one African elephant using established techniques [Bartley, 1962; Herman et al., 1975; Nachtigall, 1989]. We predicted that visual acuity would be

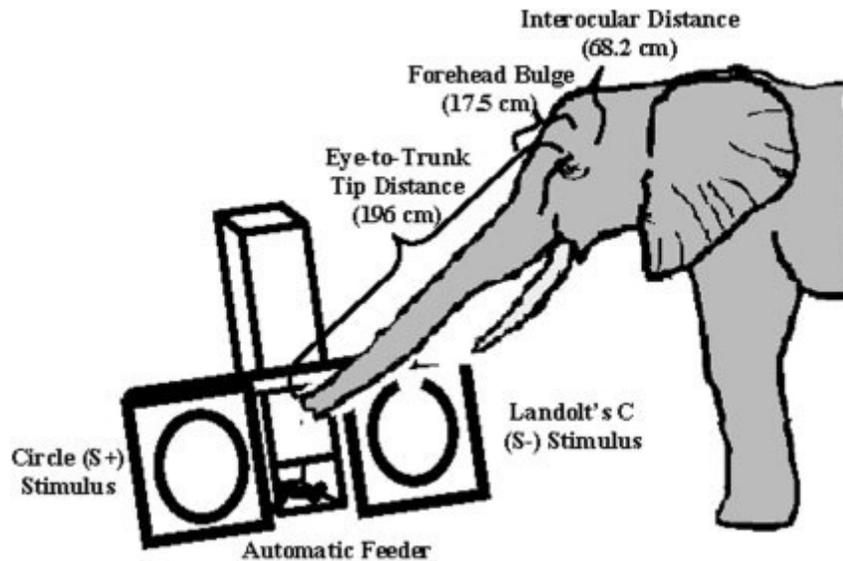


Fig. 1. Stimuli and automatic feeder distances from the elephant were determined by three anatomical dimensions.

sufficiently sensitive as to facilitate feeding, drinking, and tool use with the trunk [Chevalier-Skolnikoff and Liska, 1993; Gordon, 1966; Hart et al., 2001, 2008] and social interactions [e.g., Moss, 1982; Moss and Poole, 1983; Poole et al., 1988; Schulte, 2000; Sukumar, 2003].

Materials and Methods

Subject

Tombi was a 17-year-old female African elephant at the Indianapolis Zoo. She was not food deprived during study.

Stimuli

The discrimination test used a high-contrast black/white closed circle as the reinforced stimulus (S+) and a set of Landolt C's, high-contrast black/white open circles of uniform dimension [Bartley, 1962], as the nonreinforced stimuli (S-). The size of the gap in of the circle—the “Angle of Arc”—differed systematically across S- stimuli (see Fig. 1). We chose Landolt Cs because at lower (barn-like) illuminations they provide more sensitive visual acuity measures than several other stimuli [Bartley, 1962].

All pretesting/training stimuli were painted with nontoxic acrylic latex “Sears Best”® 30 67522 Gloss Black Enamel and 30 67512 Gloss White Enamel nonphotochemically reactive paints. Testing stimuli were computer-generated high/contrast black/white stimuli on heavy card stock. All stimuli had a 30.5 cm inside diameter. The gap in the Landolt C stimuli (S-) varied from 21.6 cm (6° 18’) to 2.2 cm (0° 39’) at an average distance of 196cm (±6cm) from Tombi’s eyes [Graham and Sorgenfrey, 1990].

Stimuli were placed in a custom-designed (Sanderson Enterprises) automatic response-reinforcement apparatus. It accepted trunk-pushes directly on each stimulus. Correct responses (S+ presses) produced a 1,000Hz tone (secondary reinforcer) and 3–30 g of monkey chow (primary reinforcer) in a box centered below the two stimuli. Incorrect responses (S– presses) produced no reinforcement and locked the apparatus to prevent “second guesses.” Training stimuli slid into plywood holders. During testing, these holders were covered by a 0.30mm thick acrylic window (for cleaning between trials). The distance between the centers of the two stimuli was 94 cm, and the center of each stimulus was 27 cm above the floor.

Stimulus Illumination

Illumination was provided by overhead fluorescent lights, skylights, and two 3.5m open doorways behind the elephant. Cloud cover and moving shadows affected the ambient light level. We controlled for stimulus illumination by randomly assigning the S+ to the left and right sides of the apparatus. This manipulation also provided methodological control for unequal light/dark ratios of the S+ and S– stimuli (S+s had a higher black/white ratio than did S–s). Ambient light level in the testing area averaged 639 lux ($n = 3$, range 486–772 lux). Reflected illumination levels from the stimulus boards to the subject’s left and her right were 289 lux ($n = 6$, range 192–400 lux) and 271 lux ($n = 6$, range 156–341 lux), respectively (digital light meter: Davis Instruments No. UN633111 Model: DLM2).

General Procedure

Tombi was stationed in front of the apparatus. A handler stood next to her, facing backwards to avoid cuing. Tombi had to push the Complete-Circle (S+) and not the Landolt C (S–). S+ and S– locations were randomized, with the restriction that the S+ not be presented in the same location more than three consecutive times. If correct, reinforcement occurred automatically. If incorrect, the experimenter (behind a blind) told the keeper, the keeper told Tombi “No,” and re-stationed her if needed. Between trials, the experimenter wiped the stimuli with a wet sponge, evenly distributing smell/mucous cues. To avoid accidental cues, the stimulus to the animal’s left was always wiped, removed, and replaced before the stimulus to her right.

In animal psychophysical tasks, low motivation, weak reinforcers, or satiation can produce falsely low estimates of sensory thresholds. To avoid this, we used a variant of the “staircase” psychophysical technique [Cornsweet, 1962]. We established a running criterion of 80% correct over 10 consecutive trials. Each time the subject met this criterion, the discrimination was made harder (Angle of Arc reduced by one step). If Tombi failed to reach criterion across 16 trials (i.e., failed to produce any 8/10 correct in 10 trials, over a 16 trial block), the task was made easier (one step larger Angle of Arc). This minimized the risk of accidentally extinguishing her response by making the discrimination too difficult. However, additional criteria were set (see below) before the elephant could move to a new phase of the study. Each new session started with the last successful stimuli from the previous session. Tombi received an average of 40 trials per day. The study had three phases:

Pretraining (Three-Dimensional S+ vs. Blank/White S–)

Initial training with flat black-and-white stimuli and response levels produced no learning, so a tactile/visual 3-D element was added and responding was changed to direct pushes on stimulus boards. We chose tactile cues as potential mediating stimuli because, with other species, researchers have used mediating stimuli to overcome similar “task-demand” difficulties [Forestall and Herman, 1988; Wright et al., 1990]. First, a 1.27 cm high (elevated) black circle S+ (2.5 cm wide, 30.5 cm diameter) was contrasted with a blank, flat, white S-. Once Tombi reached a criterion of 90% CR across two sessions, the thickness of the S+ was reduced to 0.64cm. Once she reached criterion again, the 3-D cue was eliminated. Training stimuli were introduced.

Training

The S+ remained a complete circle. The S- began as a 5.1 cm long, horizontal black arc. For both stimuli, line thickness was increased to 3.65 cm. The response criterion was changed to 85% CR during one session. When criterion was reached, the S- was systematically modified in 2.5 or 5.0 cm increments to increase the length of the black “C” shape presented. Once the gap in the S- reached 90°, testing began.

Testing

Testing with the computer-generated comparison stimuli continued with increasingly difficult discriminative stimuli until Tombi reached chance performance (50% CR) across two sessions.

Results and Discussion

Tombi received 489 test trials across 13 sessions. Table 1 shows critical data from sessions 10-13. Visual acuity was defined as the minimum gap for which Tombi made 75% correct responses (halfway between guessing, 50% CR, and perfect accuracy, 100% CR). This occurred with a 2.75 cm gap at a distance of 196 cm (Angle of arc = 48°), indicating that Tombi could see a small object (2.75 cm) at the tip of her trunk. This initial estimate of visual acuity is better than that proposed by some prior literature [e.g., Nissani et al., 2005; Savage et al., 1994], but worse than the visual acuity observed with Asian elephants. Bennett [1987] reported that two female Asian elephants had visual acuities of 8' and 8'4" at 213 and 216 cm, respectively, a 0.50 cm gap, and that Altevogt [1955] obtained a visual acuity of 10'20" of arc at 163 cm distance, also a 0.50 cm gap, with a male Asian elephant. It is not clear whether the observed difference between African elephant and Asian elephants reflects species differences, methodological differences (the previous studies used black/white grid discrimination tasks while we used Landolt Cs), or individual subject differences. The visual acuity for Tombi, measured behaviorally, was also not as good as a theoretical estimate [Stone and Halasz, 1989] based on eye anatomy [about 15'; see Kirk and Kay, 2004].

Our results lend support to the hypothesis that extra ganglion cell concentrations in the upper temporal retina of African elephants relate to visual monitoring [Stone and Halasz, 1989]. They are consistent with suggestions that the elephant's visual acuity must be high enough to recognize visual displays by conspecifics during social interactions [Langbauer, 2000; Schulte,

Table 1. Proportion of correct responses (CR) by Tombi during sessions 10-13 and the overall response accuracy for the Landolt-C stimuli with the smallest gap sizes (Angles of Arc)

Gap size (Angle of Arc)	Proportion of correct responses				Overall accuracy (% CR)
	Session 10	Session 11	Session 12	Session 13	
2.90 (51°)	3/4	9/10	—	—	86%
2.75 (48°)	8/10	3/4	8/11	1/2	74%
2.48 (43°)	10/16	8/10	2/5	—	65%
2.28 (40°)	5/14	—	—	—	36%

2000] and that highly social species may use well-developed visual systems [Savage et al., 1994].

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