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Stimulus discrimination by horses under scotopic conditions

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ABSTRACT

Scotopic vision in horses (*Equus caballus*) was investigated using behavioral measurements for the first time. Four horses were tested for the ability to make simple visual discriminations of geometric figures (circles and triangles) under various brightness levels within an enclosed building. Measurements of brightness ranging from 10.37 to 24.12 magnitudes per square arcsecond (mag/arcsec^2; in candelas per square meter—7.70 to 2.43E-05 cd/m^2) were taken using a Sky Quality Meter. These values approximated outdoor conditions ranging from twilight in open country to a dark moonless night in dense forest. The horses were able to solve the discrimination problems in all brightness settings up to 23.77 mag/arcsec^2 (3.35E-05 cd/m^2). Moreover, they easily navigated their way around obstacles located within the testing area in extremely dim light (>23.50 mag/arcsec^2; 4.30E-05 cd/m^2), which were in conditions too dark for the human experimenters to see. These findings support physiological data that reveal a rod-dominated visual system as well as observations of equine activity at night.

1. Introduction

Several aspects of vision in horses (*Equus caballus*) have been investigated including color vision (Pick et al., 1994; Macuda and Timney, 1999; Smith and Goldman, 1999; Carroll et al., 2001; Hanggi et al., 2007), interocular transfer (Hanggi, 1999a), visual acuity and depth perception (see Timney and Macuda, 2001; Waring, 2003 for reviews). However, to date, documented information on equine scotopic vision is limited. Most of what is known regarding functional night vision is based on observation, e.g., horses continue to graze, ambulate and interact at night (Berger, 1986; Mayes and Duncan, 1986). Indeed, wild Mustangs are able to run at full gallop over rough terrain while negotiating sagebrush, rocks, hills and gullies with only starlight to guide them (Hanggi, unpublished data). Timney and Macuda (2001) noted that, although no behavioral data have been collected on horses' visual performance in low light, there are indications of functional scotopic vision based on physiological factors. These features include a retina with considerably more rods than cones – an approximately 9:1 rod-to-cone ratio (François et al., 1980) and a tapetum lucidum – a fibro-elastic reflective structure that increases light-gathering properties by reflecting light back through the photoreceptor layer (Ollivier et al., 2004).

Electroretinographic studies provide additional evidence of a rod-dominated system (Wouters and De Moor, 1979) and, based on measurements of maximum pupil diameter, Hughes (1977) reported that horses have light gathering powers similar to that of dogs, gray squirrels and owls, which rank lower than cats, bats, rats, and rabbits. These factors collectively suggest adequate, if not superior vision in dim light. However, the tapetum lucidum, while allowing for increased sensitivity to dim light, may also reduce visual discrimination due to light scattering (Hebel, 1976). This is noted in cats, whose visual contrast sensitivity in low light is worse than that of humans (Pasternak and Merigan, 1981).

In daylight, horses notice small stimuli better on overcast days than on sunny days, which suggests that bright outdoor conditions may be less favorable to the rod-dominated equine eye (Saslow, 1999). Nonetheless, horses possess keen enough vision in both artificial and natural light to discriminate a broad assortment of stimuli. In experimental situations, their visual abilities are more than sufficient for solving discrimination problems of a wide variety including not only natural objects but complex computer-generated stimuli as well (see Hanggi, 2006 for a review). This allows for the investigation into higher order learning abilities such as categorization learning, conceptualization and memory, all of which have stimulus discrimination at their foundation (Sappington and Goldman, 1994; Hanggi, 1999b, 2003; Hanggi and Ingersoll, 2009). The ability of horses to make visual discriminations and, therefore, use cognitive skills under low light conditions (moonlight, starlight and dark enclosures) has not been investigated until now. While observational data are essential, behavioral measurements under controlled settings are necessary to provide a comprehensive understanding of how well horses see in low light.

In the present study, we attempted to determine if horses could discriminate simple geometric figures presented under low light

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conditions comparable to moonlight or starlight and in near darkness.

2. Materials and methods

2.1. Animals

Four horses were used in this experiment: Jasper, a 13-year-old Missouri Fox Trotter gelding; Tequila, a 12-year-old Arabian gelding; Bodie, a 12-year-old Pinto Draft mix gelding; and Callie, a 19-year-old Arabian mare. These horses lived with eight others at the Equine Research Foundation, Aptos, CA. When not being tested, they were either involved in eclectic horsemanship and positive reinforcement training, being ridden, or in pasture with herd mates. They were fed 6.8 kg grass hay daily and not food deprived prior to experiments.

2.2. Apparatus and procedure

The testing apparatus, located in a windowless metal building, consisted of a 2.5 m × 3.6 m wooden wall containing two 30 cm square openings 1.2 m apart and 0.8 m up from the bottom. A light-sealed door was located to the right of these openings, which allowed for ingress and egress. Each opening contained an opaque plastic panel that could slide horizontally to reveal the stimuli. Two hidden operators controlled placement of the stimuli and panel movement from within a light-sealed room behind the apparatus. These operators made the same movements and noises during all trials, regardless of whether stimulus position changed or remained the same. A station, located 2.4 m in front of the apparatus, served as a holding area where the horse stood unattended until it was given a release cue to approach the apparatus (Fig. 1A). This release was the lowering of a horizontal polyvinyl chloride (PVC) bar that spanned in front of the horse and was controlled via a pulley system from behind the apparatus. Food reinforcement was delivered from behind the apparatus via a chute to a feed bowl centered at the base of the apparatus.

The stimuli were laminated computer-generated images printed on 18.7 cm × 20.0 cm cards. They consisted primarily of black circles or triangles on white backgrounds but white circles or triangles on black backgrounds were also tested for a subset of luminances with three of the horses. Area of each circle and triangle equaled 227 cm^2. Circles were designated the positive stimuli (S+) and triangles the negative stimuli (S-) for Bodie and Tequila; triangles were designated the S+ and circles the S- for Jasper and Callie. The stimulus cards were placed into 33 cm square Plexiglas folders transparent on the viewing side and white on the back. These folders were placed behind the closed panels by sliding them along a track mounted to the back of the apparatus.

The stimuli were lit using two color corrected lights for natural daylight (100 W Chromalux full spectrum lamps) controlled by a rheostat switch. Because we were interested in determining how well horses see objects in dim light, and wanted to relate these findings to natural outdoor conditions, we recorded luminance measurements using a Sky Quality Meter (SQM; made by Unihedron; Cinzano, 2005), which measures brightness of the night sky in magnitudes per square arcsecond ($mag/arcsec^2$). The SQM is sensitive only to visual light and contains a near-infrared blocking filter in front of the sensor. Absolute precision of the SQM was ±0.10 $mag/arcsec^2$ and was calibrated using a NIST-traceable light meter. SQM $mag/arcsec^2$ (a logarithmic measurement) were also converted to the more traditional luminance measurements of candelas per square meter (cd/m^2) using the formula: $cd/m^2 = 10.8 \times 10^{(-0.4*[mag/arcsec^2])}$.

During testing, the horse was observed and data collected from the room behind the apparatus via shielded IP56 B&W Security Cameras with Night Vision. Probe trials, during which the cameras were disconnected, were run throughout the experiment in order to ensure that the cameras did not affect the horses' responses. The horses responded the same to the stimuli regardless of whether the cameras were turned on or off.

Each horse had been trained through the Equine Research Training System™ (ERTS) to work without human interaction (Hanggi, 1999a,b, 2001, 2003, 2006, 2007; Hanggi and Ingersoll, 2009) so that prior to the start of each trial the horse positioned itself in the station. This, as well as the stimulus discrimination training, was done in a lighted stable breezeway using a similar apparatus, which had been used in a number of other studies (Hanggi, 1999a, 2001, 2003; Hanggi et al., 2007).

During the current experiment, a trial began when the two panels opened simultaneously to reveal the stimuli. Stimulus observation time in station was 5 s, after which the release bar was lowered and the horse then walked to the apparatus where it made its choice by touching a stimulus with its nose (Fig. 1B). The horse remained at the stimulus until it heard the conditioned reinforcer "Good" or was told "No." If correct, the horse received a food reinforcer of 15 g of Nutrena Naturewise dry cob (a mixture of corn, oats, and barley). After eating the dry cob or hearing "No," the horse returned on its own to the station. Sessions were run 4 days per week on average, lasted 45–90 min, and consisted of 30–60 trials. Number of trials per session depended on level of testing and the traits of the different horses, e.g., each horse had its own preferred pace of working.

Criterion for discrimination learning was 80% correct responses for two consecutive runs of 20 trials (16/20 correct, $z = 2.68$, $n = 20$, $\alpha = 0.01$, binomial test). Trials were initially controlled for position biases and then run according to a random series (Hanggi, 1999a,b, 2001, 2003, 2007; Hanggi and Ingersoll, 2009; Hanggi et al., 2007). Once testing for scotopic vision commenced, horses were placed into the testing area and allowed to adapt to the starting level of darkness for a minimum of 15 min. This period was determined by the horses' ability to easily move around within the testing area. Testing for scotopic vision occurred incrementally: if the horse scored above 80% for a given luminance then the area was darkened and testing continued until the horse was no longer able to make the discrimination significantly above chance.

3. Results

Training of the discrimination of black circles vs. black triangles (both on white backgrounds) or, conversely, black triangles vs. black circles occurred in a nearby stable where other experiments had been conducted. All four horses learned their discriminations within 2–4 sessions (20–30 trials per session) and immediately transferred correct responding when presented with white shapes on black backgrounds. By the time the horses were put into the enclosed metal building, they were familiar with the procedure as well as a similar apparatus. Although the metal building was a new environment, the horses adapted to these surroundings and the new apparatus relatively quickly. Only Callie showed some degree of nervous behavior (raised alertness) early on but still performed well.

Because of the sensitivity of the SQM and the rheostat switch it was impossible to match precisely the variable lighting from horse to horse. However, measurements did fall into categories close enough for comparison. The results of testing under various lighting or brightness conditions are shown in Figs. 2–6. Scotopic vision testing began at brightness readings of 10.37 to 11.99 $mag/arcsec^2$ (7.70 to 1.83 cd/m^2), which were measured with lights fully on.