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Vision in Animals - What do Dogs and Cats See?

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Virtually every veterinarian has been asked, "How well does a dog or cat see?" This is a deceptively simple question, however, because even though preservation of vision is the driving force in the treatment of many ocular diseases, and the veterinarian is assumed to be well versed in the area, the visual ability of normal animals is seldom discussed in the veterinary literature. Here the constituent parts of vision (the ability to perceive light and motion, visual perspective and field of view, depth perception, visual acuity, and color vision) are described, but the complete visual experience is a synthesis of all of these components into a unified perception of the world.

Sensitivity to Light

Both cats and dogs are more sensitive to light than humans.[1-5] Cats are particularly well adapted for nocturnal vision as they have a minimum light detection threshold up to 7 times less than that of humans.[4] Other adaptations for nocturnal vision in cats include a tapetum that reflects up to 130 times more light than the human fundus, a vertical slit pupil, a large cornea which permits more light to enter the eye, a relatively posteriorly located lens that produces a smaller but brighter image on the fundus, a retina dominated by rod photoreceptors, and a form of rhodopsin that continues to increase in sensitivity to light for up to 1 hour. Dogs have many of the same adaptations, only to a less extreme degree, thereby allowing them to function in both bright and dim light. Although the canine minimum light threshold is not as low as that of cats, it is still well beyond that of humans.[2, 3, 5]

The tapetum greatly enhances vision in dim light by reflecting light back through the retina a second time.[1-3] The feline tapetum not only reflects light, but may also shift short wavelengths (blue) to wavelengths that are closer to rhodopsin's maximal sensitivity. This fluorescent shift brightens a blue-black evening or night sky, and enhances the contrast between the sky and objects silhouetted against it.[6] The superiorly located tapetum lucidum may also brighten the view of the usually darker ground, and the inferiorly located, normally darkly pigmented tapetum nigrum reduces light scattering originating from a bright sky. The canine tapetum is a less efficient reflector than that of cats, but its enhancement of vision in dim light is still undoubtedly substantial.

Sensitivity to Motion

Both animals and people are more sensitive to moving objects than stationary ones. In a 1936 study of 14 police dogs, the most sensitive dogs could recognize moving objects at 810 to 900 meters away, but could recognize the same object, when stationary, at only 585 meters or less.[2] Although humans are 10-12 times better than cats at detecting motion in bright light because of the presence of a cone-rich fovea,[7] domestic mammals may have superior motion detection in dim light, when an object is viewed peripherally, or when the object moves at a speed to which the retina is particularly attuned. Because the large peripheral visual field of dogs and cats probably only detects "movingness" or "brightness", most dogs and cats ignore stationary objects in their peripheral visual field but reflexively chase them if they move.

Sensitivity to Flickering Lights

The frequency at which a rapidly flickering light appears to be constantly illuminated (flicker fusion) provides insight into the functional characteristics of an animal's rods and cones. Flicker fusion is crudely correlated with the rapidity with which the retina can up-date an image, and generally the more rapidly a species naturally moves through its environment the higher its flicker fusion frequency. Some falcons have flicker fusion rates in excess of 100 Hz.[a] Because dogs can detect flicker at 70 to >80 Hz,[8] a television screen which is updated 60 times/sec and appears as a fluidly moving story line to most humans may appear to rapidly flicker to a dog.

Visual Perspective

Obviously, height of the eyes above the ground has a major impact on the perception an animal has of its environment, and this height varies in dogs from less than 8 inches at the shoulder to more than 34 inches.[9] This means a field of tall grass may appear as impenetrable brush to a Shih Tzu; whereas, an Irish Wolfhound visually orients itself in the same field with no difficulty. Some breeds, such as the English Springer Spaniel, may have developed behavioral traits, such as leaping into the air while searching for objects, which may serve to enhance their visual perspective.

Visual Field of View

The extent of the visual field in dogs (i.e. the area that can be seen by an eye when it is fixed on one point) also varies by breed.[10] In brachycephalic breeds where the nose is shorter and the eyes are more laterally placed, the extent of the visual field and amount of binocular overlap are undoubtedly different from that of mesocephalic breeds who have longer noses and more forward looking eyes.[10] The visual field of view of the average dog, however, is estimated to be 240 degrees (versus 200 ° in cats and 180° in humans),[11] suggesting that, with each eye, the typical dog can see from 120° ipsilateral to between 15 and 30° contralateral, for a total monocular field of view of 135 to 150°.[11] This wide field of view increases the ability of dogs to scan the horizon.

Depth Perception

Depth perception is enhanced when the visual fields of the 2 eyes overlap. Merely viewing an object with both eyes simultaneously, however, does not guarantee improved depth perception. Stereopsis (binocular depth perception) results when the 2 eyes view the world from slightly different vantage points and the resulting image is fused into a single image. If the 2 images are not fused, double vision may result. Most dogs probably have 30-60° of binocular overlap (versus approximately 140° cats and humans). Animals and humans with only one eye, however, still have the ability to perceive depth.[12] Monocular clues relating to depth include relative brightness, contour, areas of light and shadows, object overlay, linear and aerial perspective, density of optical texture, and motion parallax.[12]

Visual Acuity

Visual acuity refers to the ability to see the details of an object separately and unblurred.[1, 2] Visual acuity depends on the optical properties of the eye, the retina's ability to detect and process images, and the ability of higher visual pathways to interpret images sent to them.[1, 2] In normal animals, visual acuity is usually limited by the retina.[13]

Optical factors in visual acuity

In humans, failure of the clear optical media (cornea, aqueous humor, lens, and vitreous humor) to properly focus light on the retina commonly results in refractive errors and astigmatism which require correction with contact lenses or spectacles if the visual acuity of the eye is to be optimized. If light is focused in front of the retina, myopia (near-sightedness) results, whereas if it is focused behind the retina hyperopia (far-sightedness) occurs. The extent of a refractive error can be expressed by the formula, diopters = 1/f, where f equals the focal length (in meters) of either the lens or optical system as a whole. Therefore, an eye that is 2 diopters (D) myopic is focused 1/2 meter in front of the eye. The average resting refractive state of cats and dogs is near emmetropia, but some individuals can be significantly myopic.[14, 15] Breed predispositions to myopia were also found in German Shepherds and Rottweilers. German Shepherd guide dogs had a significantly lower frequency of myopia versus that in German Shepherds in the general clinic population suggesting that visually demanding training may "weed out" dogs with refractive errors, and that it may be reasonable to screen these dogs for refractive errors prior to their entering into a guide dog program.[14] Astigmatism, which results when the media fail to focus parallel rays of light in a uniform fashion, is generally uncommon in dogs and cats.

Adjustable focusing (accommodation) is needed if objects at different distances are to be seen with equal clarity.[3] This ability is generally believed to be quite limited in dogs and cats, and probably does not exceed 2-3D (50 to 33 cm) in dogs or 4D (25 cm) in cats.[a, 3, 15] This may explain why dogs and cats use other senses, such as smell or taste, to investigate very near objects. For comparison, young children can accommodate up to 14D or to about 7 cm.[16]

Loss of the lens, as occurs after cataract surgery, results in severe hyperopia (-14D), and a reduction in visual acuity to 20/800 or worse unless a corrective lens is used.[17] This degree of hyperopia can be simulated by setting a direct ophthalmoscope to -14D and viewing the room through the view-port. Surprisingly, although -14D hyperopia is debilitating to some dogs, most are still able to visually navigate in their environment. They would not, however, be able to perform visually challenging tasks without a corrective contact or intraocular lens.

Retinal factors in visual acuity

Enhanced vision in dim light typically requires a greater number of photoreceptors to synaptically converge on a single ganglion cell. In primates, the peak ratio is 1 cone per ganglion cell in the fovea, whereas in cats the peak ratio is 4 cones for each ganglion cell.[18] Although the greater convergence in cats increases the detection of light, it also reduces visual acuity, just as high speed film produces a "grainy" image in bright daylight. In all species there are fewer ganglion cells the periphery of the retina than in the center, resulting in reduced visual acuity in the peripheral visual field.

The topographic distribution of the photoreceptors is different between humans (who have a densely packed fovea) and dogs and cats who have a visual streak.[19-21] The visual streak is located slightly superior and temporal to the optic nerve in the tapetal zone, and has a oval region temporally with a short temporal and longer nasal extension. The tapetal location further enhances vision in dim light, but light scattering in bright light degrades visual acuity. The oval temporal region of the streak may subserve binocular vision, and the nasal linear extension of the streak may facilitate scanning of the horizon, thereby allowing the dog to better use its wide field of view.[19]

Additionally, among domesticated dogs, 2 different types of visual streaks have been found and both forms can occur within the same breed. Some dogs, and apparently all wolves, have a pronounced visual streak with a dense central area and extensions far into the temporal and nasal portions of the retina.[19] Alternatively, some dogs have a smaller, less densely packed, moderately pronounced visual streak .[19, 21] Wolves also generally have a greater maximum density of ganglion cells (12,000-14,000/mm^2) than do most dogs (6,400-14,400/mm^2).[19, 21] These features imply that the visual acuity of wolves may be better than that of dogs, and that the consistent appearance of the visual streak in wolves may be a result of environmental pressures in their natural state. Similarly, the variation in appearance of the visual streak in domesticated dogs may be the result of breeding programs that place little selective pressure on maximizing visual performance.[19]

Estimates of Visual Acuity

The Snellen fraction is a common method of describing visual acuity in humans, with the normal person having a visual acuity of 20/20. This ratio means that the test subject can discern the details of an image (letters on a chart) from 20 feet away that a normal person could differentiate from 20 feet away. When this scheme is applied to animals, the visual acuity of the typical dog is about 20/75, and the average cat is between 20/100 and 20/200.[1, 17, 22] This means that from 20 feet away, normal dogs could distinguish the details of an object that a person with normal vision could differentiate from 75 feet away. The most common methods of evaluating vision in animals (a menace response or following a cotton ball) only crudely estimate visual acuity because they test the motion sensitivity of virtually the entire retina. Positive responses with these techniques may still be present even if visual acuity is less than 20/800 and a person with such vision would be legally blind. It also must be remembered that visually distinguishing the details of an object is less important for a dog or cat's lifestyle than it is for people, and that improved vision in dim light allows the exploitation of ecological niches inaccessible to us.

Color Vision

Recent studies suggest that dogs, and to a lesser extent cats, possess and use color vision, although they have many fewer color sensitive cone photoreceptors than do humans.[23-25] Dogs appear to be similar to humans who lack green cones and are "red-green color-blind", whereas cats have a limited, but detectable capacity for color vision if the stimuli are large and differ greatly in spectral content (color).

Dogs have 2 main types of cone photoreceptors, one which is maximally sensitive to violet wavelengths (429 to 435 nm), and the other which is maximally sensitive yellow-green light (about 555 nm).[23-25] Although it is not known whether dogs perceive these 2 colors in the same way as people do, the canine visible spectrum may be divided into 2 hues: one in the violet to blue-violet range (430 to 475 nm), which is probably seen as blue by dogs, and a second in the range seen by people as greenish-yellow, yellow, and red (500 to 620 nm wavelengths), which is probably seen as yellow by dogs.[23] Dogs also appear to have a narrow band in the blue-green range (475-485 nm) that is without color and seen simply as shades of white or gray (a spectral neutral point).[23] Wavelengths at the two ends of the spectrum (blue at one end and yellow at the other) probably provide the most saturated colors. Intermediate wavelengths are less intensely colored, appearing as if they were blends with white or gray. Dogs differ from a "red-green color blind" human, however, in that the fewer numbers of cones provide less color saturation and the canine spectral neutral point is shifted towards the blue end of the spectrum (480 nm), whereas, in people the spectral neutral point is in a greener (505 nm) region of the spectrum.

Limitations in color vision are probably of little consequence to dogs and cats in dim light, however, as insufficient light is available to stimulate cone photoreceptors.[1-3] It may be problematic, however, to teach dogs to distinguish among red, orange, yellow, and green objects solely on the basis of color. Additionally, a guide dog would be unable to differentiate among the signals at a stop light on the basis of color alone. In these cases, other clues such as position, relative brightness, or smell, taste, and texture, must be used differentiate between similarly colored objects. On the other hand, dogs have been reported to be able to differentiate perfectly among closely related shades of gray that are indistinguishable to the human eye.[3] This ability would be a greater aid in visual discrimination in low light levels than would enhanced color vision which requires bright light.

Footnotes

[a] C.J. Murphy, School of Veterinary Medicine, University of Wisconsin, Madison, Wisconsin: Unpublished data.

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