DO DOGS REALLY SEE IN BLACK & WHITE? FACTS & MYTHS ABOUT ANIMAL VISION

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Veterinarians are frequently confronted by questions such as "Why do cats see better at night?", "Is it true that dogs are colour blind?", or "How sharp is my dog's eyesight?" Vision is a very complex sense that is affected by numerous factors, varies greatly between species and can be evaluated in numerous ways, so there is no simple answer to these questions. This talk will not provide a comprehensive and detailed discussion of the subject, but instead will focus (pun intended) on some of the significant differences in vision between humans, dogs, cats and horses.

1. **WHY DOES MY PET SEEM TO BE UNINTERESTED IN WATCHING TV?**

Responses to rapidly flickering lights are generated by cones. In between flickers cones undergo a brief process of recovery that enables them to generate the response to the next flicker. When the flickers become too rapid, the cones are unable to recover sufficiently between flashes. At this point, the responses of the cones "fuse", and they generate just one response to a series of rapid flashes. In humans, cone responses fuse at 45 Hz. Therefore, pictures generated by computer or TV screens, which flicker at 50 or 60 Hz, are perceived as one continuous image. However, in animals cone responses fuse at 70 - 80 Hz. Therefore, when watching television, pets can perceive individual flickering images, which probably have a dramatic effect on their interest in the program! Similarly, pets can detect the flickering of fluorescent lights, a fact that should be taken into account when designing the lighting of your clinic. Yellow, incandescent bulbs that do not flicker provide for a friendlier environment, at least as far as the patient's vision is concerned.

2. **DOES MY PET HAVE COLOUR VISION?**

Colour vision is the domain of the cone photoreceptors. Based on wavelength sensitivity of the photopigment contained in their outer segments, four types of cones have been identified, with animals having anywhere from one to all 4 populations. The number of cone populations, and the degree of overlap in the absorbance spectrum of their photopigment, determine an animal's colour vision capabilities. Humans have 3 cone populations, with peak absorbance in the blue, green and red wavelengths (and this is why these are our 3 primary colours), thus making us a *trichromatic* species. Some species are *monochromatic*, having just one cone population, making them red, green or blue monochromats. Such a retina can be found in many nocturnal species, and their colour vision is limited to shades of that single photopigment. At the other end of the spectrum, some species have 4 cones populations, with a 4th photopigment absorbing light in the ultraviolet part of the spectrum. These *tetrachomatic* species, usually fish and birds, consequently have a much richer colour vision than we do.

Contrary to prevalent public opinion, dogs and cats do not "see in black and white". Dogs have two populations of cones. One population absorbs light in the blue-violet spectrum, while the second population absorbs light in the red spectrum. Therefore, dogs can see colours, but are unable to distinguish between green shades. Similarly, cattle & horses have cones absorbing in blue and in green wavelengths, but are unable to see red shades of colour (which means that bulls do not perceive the colour of the red cloth used by bullfighters). Colour vision in all of these species is analogous to that of "colour blind" humans. Colour blind people are rarely truly colour blind. In most cases, they are missing either the red or the green cone population, making them, and the respective species, *dichromats*. Whales and other aquatic mammals are unique dichromats, who are missing the blue cone population. This means that these species can not appreciate the blue shade of their aquatic environment! Cats, on the other hand, have 3 cone populations. However, numerous behavioral studies failed to reveal rich trichromatic colour vision in felines.

3. VISUAL FIELDS

There are two types of visual fields. The binocular visual field is frontal, and it is the area in which there is overlap of the visual fields of both eyes. Traditionally, this binocular input is required for depth perception. The monocular visual field is the lateral visual field of each eye, in which there is no input from the other eye. The size (or extent) of the monocular and binocular visual fields is largely determined by the placement of the orbits and eyes in the skull. Herbivores have lateral orbits, giving them a small, frontal binocular field of vision, and two large, lateral monocular fields (providing them with almost 360° panoramic vision). The large lateral monocular fields are important to these species as most of them are prey species that need to see approaching predators. The evolutionary price tag of having a small area of binocular vision has little consequence for these species, as their feeding behavior requires little depth perception. On the other hand, species with frontal facing eyes (primates, raptors, companion animals and many predator species) have a large binocular frontal visual field, which is essential for catching prey. Monocular, panoramic fields are less important to these species that need to focus on prey rather than avoid predators. The total visual field of cats, for example is estimated at 200°, including a 140°, central binocular field, and two lateral, monocular fields of 30° each. Horses, on the other hand, are estimated to have a visual field of about 355°, including central binocular field of just 65°, but two large, lateral, monocular fields of about 145° each.

4. NIGHT VISION

Domestic animals have very sensitive night (*scotopic*) vision. Studies show that the threshold light intensity needed to elicit vision in humans is X6 the threshold intensity in the cat. Several physiological and anatomical mechanisms account for this improved visual performance in the dark. The first is the amount of light entering the eye. Animals (especially cats, cattle and horses) have very large corneas and pupils. Therefore, more light can pass through their cornea and pupil and reach the retina. It has been calculated that the amount of light that falls on a feline retina is x6 the amount of light that reaches a human retina

Furthermore, domestic animals are more capable of exploiting this light, thanks to the *tapetum lucidum*. This structure, located in the choroid, acts as a mirror. Photons that are not absorbed by photoreceptors are reflected back to the retina, thus doubling the probability that they will be absorbed. However, it should be remembered that the presence of a tapetum results in lower visual acuity, as the photons that are reflected by the tapetum are scattered in the eye and not absorbed by the photoreceptors that are in their original trajectory. In other words, the tapetum provides cats with higher sensitivity at night (when cones are inactive, and therefore reduced visual resolution is of less consequence) at a price of lower daytime visual resolution.

However, the most important factor in determining sensitivity to low light levels is the proportion of rods and cones. Rods are very sensitive to low light levels, and can function in intensities that are 10^{-5} those required by cones. As Table 1 demonstrates, cats have a much higher concentration of rods than humans throughout the retina, thus contributing significantly to their night vision, while detracting from their visual acuity.

Table 1 – Concentrations of rods and cones

	HUMAN	CAT
Maximal cone concentration (per mm2)	199,000	27,000
Maximal rod concentration (per mm2)	160,000	460,000
Cone concentration in retinal periphery (per mm2)	5,000	<3,000
Rod concentration in retinal periphery (per mm2)	40,000	250,000

5. HOW SHARP IS MY PET'S EYESIGHT?

Visual acuity, or visual resolution, is determined primarily by two factors, the optics of the eye and the anatomy of the retina. Optically, an *emmetropic* eye is one is which light is properly focused on the retinal photoreceptors. In a *myopic* (or short-sighted) eye, the image is focused in front of the retina, while in a *hyperopic* (or far-sighted) eye the image is focused behind the retina. Myopia and hyperopia are collectively known as *ammetropia*, and the image in such eyes is blurred. A recent large study in which 1500 dogs were refracted showed that a majority of dogs are emmetropic. In other words, it could be said that in these dogs the combined optical power of the eye (mainly the cornea and lens) result in a focused image on the retina, and these dogs do not require corrective spectacles. However, the same study showed that about 25% of all dogs are myopic, with a refractive error ranging from -0.5 to -6.0D. Furthermore, some dog breeds have a mean myopic refractive state the average refractive error of some breeds is myopic. For example, in poodles, 77% of dogs were myopic, with a mean refractive error of -1.8D. Even in breeds that have a mean emmetropic refractive stat, significant numbers of dogs are myopes, with more than 20% of all Labrador retrievers, German shepherds and English springer spaniels being myopic. On the other hand, significant numbers of dogs were hyperopic, with some dog breeds (e.g., Alaskan malamute) having a mean hyperopic refractive state. Ammetropia may be genetic in some breeds (e.g., Labrador retrievers), and is also affected by age, gender and living habitat (outdoors vs indoors). A study in cats showed that kittens are myopic (mean error -2.5D) but adults are close to emmetropia (-0.4D), while in horses, half of the animals studied were emmetropic, with the rest divided equally between myopia and hyperopia. All of these ametropic animals could theoretically benefit from corrective spectacles or refractive surgery.

The refractive error can also be changed actively in a process called *accommodation*. In mammals this is usually achieved by changing the curvature of the lens (in primates) or its location in the eye (in carnivores). Domestic animals are limited in their accommodative capability. Horses can accommodate by only 1D (i.e., change the refractive power of their lens by 1D when viewing nearby objects), cats by 1-3D and dogs by 2-8D. Birds, on the other hand, can accommodate by 30-60D.

However, visual acuity is also determined by retinal anatomy. As mentioned previously, the presence of a tapetum lucidum in the eye of domesticated animals causes scattering of light which reduces visual acuity in all these species. Furthermore, differences in the concentration of cones, and their associated ganglion cells, will also have an effect on visual acuity. Because in all domestic species the concentration of cones and their associated ganglion cells is lower than in humans (Table 1), their visual acuity is lower than that of primates. This means that even if a dog or a cat are emmetropic, and have a well-focused image on their retina, their visual acuity will be low, because the resolving power of the eye is reduced by the low cone and ganglion cell concentration in these species. On the other hand, raptors have higher visual acuity than humans, as they have a higher cone and ganglion cell concentration than we do.

Visual acuity is typically expressed as a *Snellen fraction*. The acuity of normal humans is 20/20. It is estimated that the visual acuity of the horse is 20/33, meaning that a horse needs to be 20 feet from an object to see it as well as a person standing 33 feet away. Visual acuity is 20/75 in the dog and 20/150 in the cat. In other words, a cat has half the acuity of a dog, and a fifth the acuity of a horse. Consequently, a cat has to be more than 7 times closer to an object to see it as sharply as we do! Again, these figures are based on the assumption that the animal is emmetropic. If an animal is ametropic, then its visual acuity will be even poorer.

6. CONCLUSIONS

Compared to humans, animals have inferior colour vision, accommodative capabilities and visual acuity. In cats, colour vision may be more similar to humans than to dogs. However, animals have superior night vision and flicker detection. They are also likely to have better motion detection and low contrast vision. These properties enable animals to see well at night, while we are left groping in the dark.