A leap in the color! How understanding horses’ color perception improves their performance and welfare in show jumping

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ABSTRACT

In horse showjumping, the probability of falls at jumps can depend on the horse capacity to see obstacles. Experimental works have confirmed the correlation between obstacle colors and jumping performance. Horses are dichromats: they can see blue and yellow, but they are not able to clearly distinguish red, orange, and green. The available results in this field, however, can be hardly compared, because the different authors have not characterized colors in terms of any standard system. Furthermore, even when the obstacle colors considered in the different research works look similar, the corresponding computer-simulated colors (i.e., how colors would be seen by the horse's eye) appear significantly different. Color design can contribute to fill some of these gaps. To this end, this paper first summarizes the horse visual system. A state-of-the-art survey on color impact on the jumping performance is reported, highlighting inconsistencies and problems that can be ascribed to a lack of familiarity with color science. A color analysis of a real jumping competition is finally presented, showing some key aspects that could be advantageously considered when the obstacle sequence is designed. The results reported in this paper represent a starting point to define a systematic approach in the color design of jumping obstacles in horse competitions.

KEYWORDS horse vision, horse-rider synergy, contrast measure

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1. Introduction

Collecting information about the surrounding environment is crucial for survival, and most animals process that information primarily through the visual system. Ecology and life conditions shaped animal visual abilities and stimuli perception leading to a wide inter-species and inter-individual variability (Veilleux and Kirk, 2014). This mostly occurs in color discrimination, which varies based on the number and type of photopigments located in the eye cones (Bowmaker, 2008). Knowing how animals perceive colors becomes essential to design products or environments for domestic species or in those activities involving human-animal coordination (Adamczyk *et al.,* 2015; Rørvang *et al.*, 2020). Showjumping is one of the most popular equestrian disciplines, attracting increasing attention on horses' welfare and safety. The probability of falls or injuries at jumps also depends on the capacity of the horse to see and respond to obstacles (Górecka-Bruzda *et al.*, 2011). The contrasting colors of obstacles with surrounding has been found to be decisive in perceiving the presence, the distance, and the size of the hurdle (Paul and Stevens, 2019). Horses (*Equus caballus*) are dichromats, with two eye cone types, sensitive to short and medium wavelengths. They can see blue and yellow, while they are not able to distinguish red, orange, and green, unless brightness, shade, texture, and other features are well integrated (Hanggi *et al.*, 2007).

The analyses of jump faults (obstacle knock-down or run-out) reported in literature confirm the correlation between obstacle colors and performance (Stachurska *et al.*, 2002). More recently, Stachurska *et al.*, (2015) and Paul and Stevens (2020) have further highlighted the relevance of other aspects, such as background colors, hurdle color schemes (monochromatic or polychromatic) and Light Reflectance Value (LRV) contrasts (Wyszecki and Stiles, 2000). However, in most of the available works the analyzed colors have not been expressed in terms of a standard color system, but only by means of generic names (like red, yellow or orange) or through pictures. Also, the models used to predict the horse color vision are, in most cases, not specified. Finally, the chromatic vision of riders, enabling them to safely navigate obstacles, could have a role as well in the performance. Nonetheless, this aspect has received little attention by researchers. This paper initially introduces the main features of the horse visual system. A literature revision on the impact of color on the horse jumping performance is reported, highlighting inconsistencies and problems that can be ascribed to a lack of familiarity with color science. Examples of obstacle color schemes (acquired by means of instrumental measurements) commonly used in jumping competitions or during training are analyzed. Finally, the paper proposes a framework with few procedural rules that can help in the design of obstacles for competitions and training. The results reported in this paper can represent a starting point to define a systematic approach in the color design of jumping obstacles in horse competitions.

1.1. *The Horse Visual System*

As prey animals, horses have evolved a visual system that allows them to constantly monitor the nearby environment; they need to detect potential predators in the long distance, to get ready to escape anytime. Their visual field has fostered a panoramic viewing system, with limited binocular capability (Timney and Keil, 1999). The binocular field of vision, which is 120° in humans, is only 55° to 65° in front of the horse (Hughes, 1977), and the overlap is predominantly below the head, extending down ~75° (Timney and Macuda, 2001). The visual input is stretched and wide, conferring a panoramic view with only a small blind spot at the rear. Horses have poorer acuity than most other terrestrial mammals, due to a low density of cones in the retina. Unlike the human's retina, the equine retina has no central fovea, while it presents what is known as a "visual strip" (Harman *et al.*, 1999). This region, projecting towards both nasal and temporal directions, is characterized by a high-density of ganglion cells (Evans and McGreevy, 2007). On the other hand, horses are hyperopic (Murphy *et al*. 2009), a characteristic which allows them to have good visual acuity for distant objects. To bring objects into focus, horses must lift, lower or tilt their heads. Whether the over-arched neck of the ridden horse in sports like dressage or showjumping would inhibit its ability to see what is directly in front of it, is a debated topic from more than a decade (Harman *et al*. 1999). Recent studies indicate that they can compensate for some head and neck rotation by rotating eyeballs; however, this does not counteract few hyperflexed positions (McGrevy *et al.*, 2010). The recent increased awareness about horse welfare and the factors affecting the performance has induced riders in showjumping to allow their horses choose their own head carriage, for a better perception of the obstacle. Finally, another anatomical feature can influence horses' perception of obstacles. The tapetum lucidum is a light-reflective tissue present in the eyes of both vertebrates and invertebrates. It serves as a biological reflector system with the primary role of boosting visual sensitivity in low-light conditions by offering a secondary chance for photon-photoreceptor interaction to the light-sensitive retinal cells (Braekevelt, 1998; Lesiuk and Braekevelt, 1983). However, while beneficial in dim lighting (Shinozaki *et al.*, 2013; Ollivier *et al*. 2004; Schwab *et al*. 2002), the tapetum lucidum can compromise visual acuity when exposed to bright illumination and potentially alter the discrimination of colors.

1.1.1. *Horses' color perception in relation to obstacles in showjumping*

Human color vision is trichromatic, i.e. photons absorb light in three classes of cones, whose peak sensitivity lie in the long-wavelength (L), middle- wavelength (M), and short-wavelength (S) regions of the visible spectrum. Total color blindness, an exceedingly uncommon condition, typically manifests as rod monochromacy, wherein the individual lacks any functional cones and therefore experiences complete absence of color vision. Alternatively, cone monochromats may possess restricted color perception, observable under circumstances where both the rods and their sole type of cones are concurrently active (Joesch and Meister, 2016). Reduced forms of color vision occur from the actual deficiency of one of the retinal photopigments (L, M, or S). Dichromatism results when the peak sensitivity of one of the primary cones shifted, and the amount of shift defines the color spans perceived. The majority of individuals with color vision deficiency exhibit dichromatic vision, where they either lack or possess a mutated form of the red (protanopia), green (deuteranopia), or blue opsin (tritanopia) receptors. Consequently, they can perceive colors, but, for instance, a protanope may find red and green objects to appear very similar in color, while being able to distinguish between blue and green (or red) objects. Similarly, most mammals, such as dogs, cats, horses, goats, sheep, and swine, are dichromats, akin to human protanopes or deuteranopes (Jacobs, 2018; Gelatt *et al.*, 2021). Horses, for instance, possess cone opsins with peak absorbance in the blue and green regions of the spectrum, resulting in color vision that resembles that of human deuteranopes (Hanggi *et al*., 2007). Along with the anatomical peculiarity of horse's eye, color perception is a pivotal aspect of the showjumping performance, most importantly for the selection of obstacle colors, as these may not be perceived by horses as they appear to the human eye, and vice versa.

In the literature, only few recent studies are available, comparing different obstacle colors without elaborating on the variability in color schemes or specific colors features. Stachurska *et al*. (2002) suggested that using white resulted in a largest takeoff distance, while bright blue produced a larger angle of takeoff; jumps over fluorescent yellow fences had shorter landing distances compared to orange. Later, Stachurska *et al*. (2015) highlighted the potential difficulty for horses to jump obstacles which are all light or all dark, since these may cause an optical illusion that leads to overestimating the obstacle size. Uniform dark may make the horse disregard the obstacle altogether. Paul and Stevens (2019) provided a comprehensive analysis of different colors and characteristics of colors in show jumping. Authors tested orange, fluorescent yellow, bright blue, or white obstacles, and found a correlation between obstacle color and both the jump angle and the jumped distance. Also, they took into consideration shade, texture, and/or brightness properties of specific colors such as white, yellow, or blue, which impact the attractiveness of these colors. Matt fluorescent yellow reliably has the highest contrast, in terms of luminance, of all the colors tested. Unfortunately, in all the available works discussed above, the authors have not adopted a standard color system to define the used colors, which are usually referred to with generic names or just shown in pictures. Moreover, the computer simulations of how the colors applied to obstacles could appear to the dichromat horses seem to provide quite different outputs, even when the input colors are similar. Sometimes the simulated colors do not seem to be reliable representations of color-blind vision, at least compared to the results commonly obtained with available color blindness simulators. This lack of uniformity and proper color references could be overcome by the adoption of standard color systems and by defining a common model for color blindness simulations.

2. Methods

To analyze the color schemes of the obstacles used in a real showjumping competition, instrumental color measurements were performed at Gorla Maggiore, Italy, 13-15 May 2022, during the "Nazionale a 5 Stelle" Jumping Trophy. Specifically, the colors of all the obstacles used in the Trophy were acquired by means of a commercial colorimeter. To further characterize the color patterns used for the obstacles, a Color Presence and a Color Distribution analysis were performed, as discussed in the following subsections.

2.1. *Color presence analysis*

In color design, the color presence analysis determines the set of colors used for a specific object. To this aim, a measurement campaign was initially performed (see Fig. 1) to acquire the colors of all the obstacles available in the competition site at Gorla Maggiore, both before and during the Jumping Trophy.

The instrumental measurements were performed using a Datacolor colorimeter, combined with the companion ColorReader software application. Fig.2 shows a screenshot of a Datacolor measurement obtained during the measurement campaign. Since obstacles are usually painted using the RAL system as a reference, all the measurements were transformed from the CIE Lab system to RAL, by exploiting the matching capability of the ColorReader application, which can provide the RAL color sample perceptually closest to the obtained color measurement (Wyszecki and Stiles, 2000). Furthermore, anomalous color vision simulations were obtained using the software tool described in (Paglierani and Valan, 2018). Fig. 3 shows an example of the color acquisition and analysis process. On the left, it shows two acquired colors, expressed according to the RAL color systems – with codes RAL 4003 and RAL 6004; on the right, the corresponding simulation, which shows how obstacle colors would presumably appear under protanopy conditions (Paglierani and Valan, 2018), with the corresponding RAL codes – RAL 5014 and RAL 6004, respectively. As already discussed, the horse visual system presents spectral sensitivity curves with peaks not far from the human ones for blue and green, and the used simulation tool allows to emulate this condition: while yellow, blue and neutrals remain almost unaffected, the pink and the green bands on the shown obstacles appear significantly modified (Paglierani and Valan, 2018).

Fig. 1. Some examples of the obstacle color acquisition process during the measurement campaign carried out in Gorla Maggiore, Italy.

Fig. 2. Screenshot of a DataReader color measurement. The corresponding RAL code is provided by the ColorReader application as the closest RAL color sample.

Fig. 3. Obstacle color acquisition and processing. On the left: obstacle colors seen by human normal vision. On the right: dichromat vision simulation.

The overall analysis showed that the obstacle colors seem to be chosen randomly, i.e. the visual features of the horse do not seem to influence in any way the color choice. Thus, the color scene as observed by the horse and the rider can result significantly different, and this could lead to a non-optimal perceptual agreement between them. Furthermore, this random choice in the chromatic composition of obstacles could lead to combinations of obstacle and background colors that can be clearly perceived by the rider, but that could result problematic to the horse. This possibility seems to be further suggested by the color distribution analysis summarized in the next subsection.

2.2. *Color distribution analysis*

The color distribution analysis identifies how colors are applied to objects. In this case, it allows characterizing the patterns used for coloring obstacles. The analyzed obstacles present a variety of different patterns, with one, two or three colors, as shown in Figure 4.

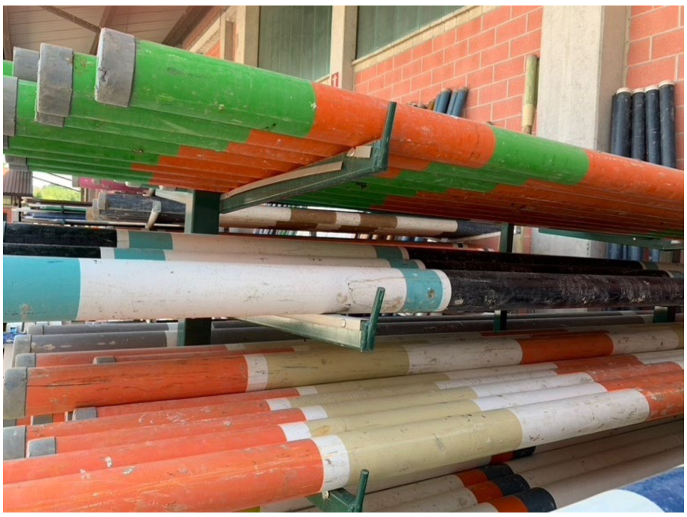

Fig. 4. Examples of obstacles with different chromatic patterns.

Quite complex shapes are sometimes included in the barriers, as well as decorations (shapes of flowers, leaves, etc., as shown in Figure 5). One fundamental aspect to consider is the contrast that the obstacle color pattern can present w.r.t. the background. Notwithstanding the complexity of most of the adopted color schemes, in some cases the obstacle results not well visible to the rider with normal vision or to the dichromat horse. In other cases, the obstacle is well visible to a normal visual system but could be less identifiable to a dichromat.

Fig. 5. Obstacle components of different shapes

Also, the role of the background seen by the couple horse-rider plays a fundamental role. The background can in fact create a visual disturbance, interfering with the barrier perception of both the horse and the rider (Figure 6).

Fig. 6. Combined visual effect of the barrier and the background.

A careful choice of the obstacle colors that considers the visual background could render the barrier more easily perceivable by horses and riders.

2.3. *Obstacle analysis examples*

To start investigating the possible impact of obstacle color on the horse jumping performance, the colors of all obstacles used in two races during the "Nazionale a 5 Stelle" Jumping Trophy were analyzed, together with the final score of each horse/rider couple, officially recorded in the report released by the race judges. Although the carried-out survey is clearly non-significant from a statistical point of view due to the small sample set, the analysis can provide useful hints for future research activities, and can sketch a methodology that, applied to a significantly larger number of competitions, will provide more reliable results. Pictures of the obstacles were also acquired in the field, together with the official obstacle sequence maps. Fig. 7 shows the number of errors for each obstacle during the first analyzed competition (May 14, 2022, time: 11 a.m., obstacle height: 135 cm; lighting conditions: sunlight, no clouds, participants: 45). The histogram clearly shows that errors are not uniformly distributed among obstacles: in particular, obstacle number 5 originated 14 errors, while at obstacle number 7 no error occurred. It must be remarked that obstacle 5 was a combination, i.e. a sequence of two obstacles judged as one jump. This type of obstacles could cause more errors than simple fences or other types of obstacles, requiring a double jump in a constraint space. However, it could be observed that in other competitions during the considered event such combinations were not the obstacles with the highest number of errors. Nonetheless, the obstacle type should be considered as a variable in the statistical analysis. Moreover, also the position of the obstacle in the field can have a role in the analysis. In this paper, however, the scope is a preliminary overview of the problem, and the impact of obstacle types and positions, as well as other factors of potential interest, will be considered only in a qualitative and comparative way. Type and position of the obstacle in the overall sequence will be further discussed in the following.

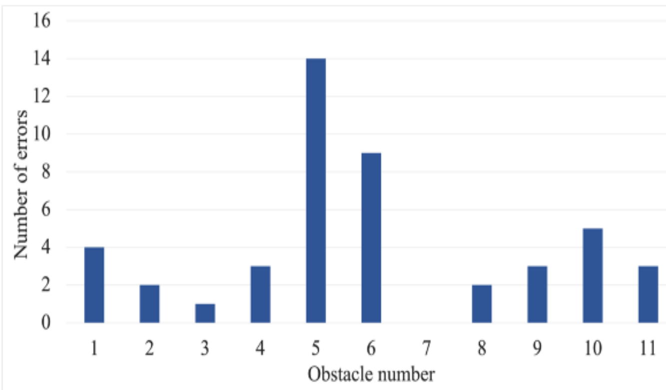

Fig. 7. Histogram of the errors observed at each obstacle (first competition).

Fig. 8. Obstacle 5 (left, max. error number), and 7 (right, min. error number) in the first analyzed competition.

Fig. 8 shows obstacles number 5 and number 7. As one can clearly see, obstacle number 5 is not easily perceivable w.r.t. the background and the ground (see also Fig. 6). This may have contributed to increase the difficulty of the jump. Conversely, obstacle 7 seems to be better perceivable to a normal visual system, and less to the dichromat horses. However, even for dichromats, obstacle 7 stands out quite clearly from the background. The results of a second jump competition are shown in Fig. 9. In this case, the obstacles were the same used in the previous competitions, but positioned differently in the race field, and in a different sequence. The height of the obstacles was 130cm, the starting time was approximately the same (11 a.m.), as well as the lighting conditions (sunlight, no clouds). The number of participants was 48. In this race also, the error distribution was not uniform, even if with a less pronounced peak than in the previous one. The highest number of errors was observed at obstacle number 7, while the obstacle with the lowest number of errors was number 3 (see Fig. 10). Quite interestingly, the same black obstacle 7 had had a low number of errors in the previous race (where it was obstacle number 9, with 3 errors) - when placed in a different position. Obstacle 7 was an oxer in this second competition, i.e. a double vertical fence with a space in the middle. Obstacle 7 was a simple fence in the previously analyzed race. The gray obstacle 3 that here had the lowest number of errors, was the one with the highest number of errors in the previous competition (obstacle number 5). However, in this race this gray obstacle was used as a single fence, and not as a combination. Also, its position in the two race paths was different, and therefore so was the contrast with the background.

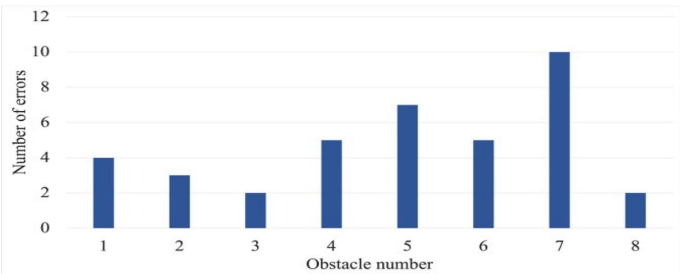

Fig. 9. Histogram of the errors observed at each obstacle (second competition).

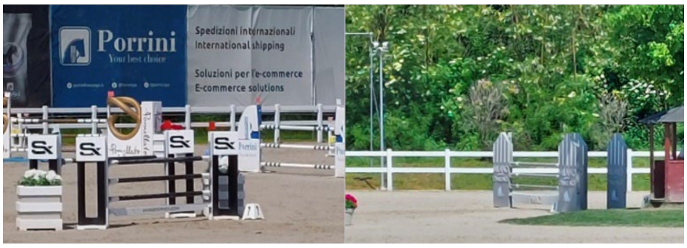

Fig. 10. Obstacle 7 (left, max. error number), and 3 (right, min. error number) in the second analyzed competition.

3. Conclusions and future perspectives

The horse jumping performance can be influenced by several parameters: color of the obstacle, contrast with the background, lighting conditions, type of obstacle (fence, oxer, combination, etc.), position in the field and in the sequence, etc. (Paul and Stevens, 2020; Stachurska *et al*., 2015). In general, the performance can be the result of a complex combination of such factors, which could be difficult to predict. The contrast of an obstacle against its surroundings and the ground seems to play an important role: it can influence the determination of obstacle presence, size, and the distance between the viewer and the obstacle (Bruce *et al*., 2003). The analyzed examples have shown that the same obstacle, positioned in different places in different races with similar lighting conditions, can originate a significantly different number of errors. Moreover, the study of the horse visual system suggests that horses could be particularly sensitive to lightness. Thus, lightness, and in particular lightness contrasts, could play an important role in the jumping performance. The finishing of the obstacle, particularly its gloss, could be also important, as gloss typically plays a role in the vision of dichromats. Nonetheless, the impact of lightness contrasts and/or gloss and finishing of obstacles on the jumping performance, to the best of the authors' knowledge, have received minor attention from researchers. The horse color vision has been analyzed for the impact it could have on the jumping performance. Conversely, less attention has been paid to the color vision of riders. Since 8% of the male population is affected by color vision deficiency, a non-negligible fraction of riders could have color vision problems, and this could affect the jumping performance or the relationship horse-rider. To the best of the authors' knowledge, this aspect has never been considered in the literature.

Some basic rules for the design of obstacle colors and their use in competition paths can be provided. The selection of colors for the obstacles that result invariant under the specific horse color blindness can help control in a more accurate way the difficulty of obstacles.

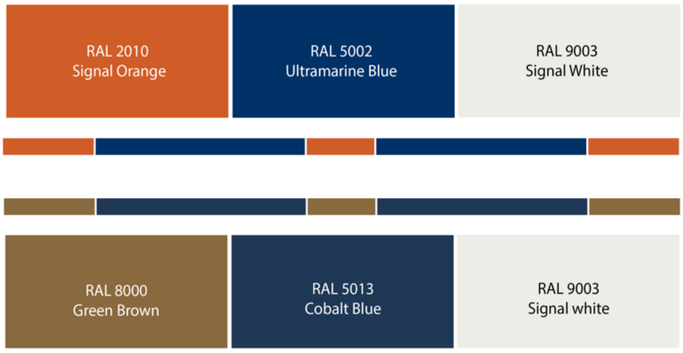

Fig. 11. Dichromat invariant obstacle design.

Fig. 11 illustrates an example of obstacle color design that considers horse color vision capabilities. The upper obstacle is a real obstacle pattern, whose vision by the dichromat horses would result distorted w.r.t. normal human vision. The lower obstacle is the simulated version of the upper one (i.e. it represents how the upper obstacle would appear to a dichromat). The color cards on the top and on the bottom of Fig.11 report the colors of the real and simulated obstacle, respectively. Using the colors of the simulated obstacle, one would obtain a real obstacle appearing invariant both to normal and to dichromat observers. Such type of obstacles could be used in experiments on the impact of colors on the jumping performance, as well as during training, to create paths with controlled visual difficulties and improve the harmony in the human-horse interaction (Scopa C., *et al*. 2019). Investigating the color vision of riders is a future line of research for this activity. This aspect has received minor or no interest from researchers. Color deficiency of the rider could offer an advantage in creating a better harmony between rider and horse, resulting in improved racing performances. One of the planned activities in the follow up of this research will be rider color vision testing to verify a possible competitive advantage of riders with color deficiency. A hint on this comes from the famous horse rider and trainer M. Roberts, who suggests that his color blindness could have helped him in his relationship with horses (Roberts, 1997).

4. Conflict of interest declaration

The authors declare that there is no conflict of interest.

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6. Short biography of the authors

Francesca Valan - Francesca is an Industrial designer specialized in Colors, Materials, and Finishes design. She graduated in Industrial Design at IED, Milan, in 1989, and received her Master in Surface Quality in 1990. She collaborated with Società di Ergonomia Applicata, investigating the aspects of visual ergonomics. She founded her studio in 1998 and she teaches Color Design Technology at Milan University.

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Chiara Scopa - Chiara is a Ph.D. student in Neuroscience, Behavioral Biology at the University of Parma. She has conducted behavioral analysis on different aspects of horses' behavior, from self-awareness to emotional interactions with humans. She is now working on a multidisciplinary project, aiming at determining the relation between the level of maternal milk exposure to environmental chemicals and infants' neurobehavioral development.

Licensing terms

References

Adamczyk, K. *et al.* (2015) "Perception of environment in farm animals-A review", *Annals of Animal Science*, 15(3), pp. 565. : doi.org/10.1515/aoas-2015-0031.

Braekevelt, C. R. (1986) "Fine structure of the tapetum cellulosum of the grey seal (*Halichoerus grypus*)", *Acta anatomica*, 127(2), pp. 81-87. doi.org/10.1159/000146260.

Bowmaker, J. K. (2008) "Evolution of vertebrate visual pigments", *Vision research*, 48(20), pp. 2022-2041. doi.org/10.1016/j.visres.2008.03.025.

Evans, K.E. and McGreevy, P.D. (2007) "The distribution of ganglion cells in the equine retina and its relationship to Skull Morphology," *Anatomia, Histologia, Embryologia: Journal of Veterinary Medicine Series C*, 36(2), pp. 151–156. doi.org/10.1111/j.1439-0264.2006.00749.x.

Gelatt, Kirk N., Janice P. Gelatt, and Caryn Plummer. Veterinary Ophthalmic Surgery-E-Book. Elsevier Health Sciences, 2021.

Górecka-Bruzda, A. *et al.* (2011) "Looking for an ideal horse: Rider preferences," *Anthrozoös*, 24(4), pp. 379–392. doi.org/10.2752/175303711x13159027359827.

Hanggi, E.B., Ingersoll, J.F. and Waggoner, T.L. (2007) "Color vision in horses (*Equus caballus*): Deficiencies identified using a pseudoisochromatic plate test", *Journal of Comparative Psychology*, 121(1), pp. 65–72. doi.org/10.1037/0735-7036.121.1.65.

Harman, A.M., *et al.* (1999) "Horse vision and an explanation for the visual behaviour originally explained by the 'Ramp Retina,'" *Equine Veterinary Journal*, 31(5), pp. 384–390. doi.org/10.1111/j.2042-3306.1999.tb03837.x.

Hughes, A. (1977) "The topography of vision in mammals of contrasting life style: Comparative Optics and retinal organisation," *The Visual System in Vertebrates*, pp. 613–756. doi.org/10.1007/978-3-642-66468-7_11.

Jacobs, G. H. (2018) "Photopigments and the dimensionality of animal color vision", *Neuroscience & Biobehavioral Reviews*, 86, pp. 108-130. doi.org/10.1016/j.neubiorev.2017.12.006

Joesch, M., and Meister, M. (2016) "A neuronal circuit for colour vision based on rod–cone opponency", *Nature*, 532(7598), pp. 236-239. doi.org/10.1038/nature17158.

Lesiuk, T. P., and Braekevelt, C. R. (1983) "Fine structure of the canine tapetum lucidum", *Journal of anatomy*, 136(1), pp. 157.

McGreevy, P.D. *et al.* (2010) "Over-flexing the horse's neck: A modern equestrian obsession?," *Journal of Veterinary Behavior*, 5(4), pp. 180–186. doi.org/10.1016/j.jveb.2010.03.004.

Murphy, J., Hall, C. and Arkins, S. (2009) "What horses and humans see: A comparative review," *International Journal of Zoology*, 2009, pp. 1–14. doi.org/10.1155/2009/721798.

Ollivier, F.J. *et al.* (2003) "Connective tissue growth factor in tear film of the horse: Detection, identification and origin," *Graefe's Archive for Clinical and Experimental Ophthalmology*, 242(2), pp. 165–171. doi.org/10.1007/s00417-003-0802-x.

Paul, S.C. and Stevens, M. (2020) "Horse vision and obstacle visibility in horseracing," *Applied Animal Behaviour Science*, 222, p. 104882. doi.org/10.1016/j.applanim.2019.104882.

Paglierani, P. and Valan, F. (2018) "A digital framework for color design and education", Cultura e Scienza del Colore - Color Culture and Science, 10, pp. 93–101. doi: 10.23738/ccsj.i102018.11.

Rørvang, M.V., Nielsen, B.L. and McLean, A.N. (2020) "Sensory abilities of horses and their importance for equitation science," *Frontiers in Veterinary Science*, 7. doi.org/10.3389/fvets.2020.00633.

ROBERTS, M.O.N.T.Y. (2099) *Man who listens to horses*. S.l.: HUTCHINSON.

Schwab, I. R. et al. (2002) 'Evolution of the tapetum', Transactions of the American Ophthalmological Society, 100, pp. 187. PMID: 12545693; PMCID: PMC1358962.

Scopa, C. *et al.* (2019) "Emotional transfer in human–horse interaction: New perspectives on equine assisted interventions," *Animals*, 9(12), p. 1030. doi.org/10.3390/ani9121030.

Shinozaki, A. *et al.* (2013) "The fibrous tapetum of the Horse Eye," *Journal of Anatomy*, 223(5), pp. 509–518. doi.org/10.1111/joa.12100.

Stachurska, A. *et al.* (2015) "Does music influence emotional state in race horses?," *Journal of Equine Veterinary Science*, 35(8), pp. 650–656. doi.org/10.1016/j.jevs.2015.06.008.

Stachurska, A., Pięta, M. and Nesteruk, E. (2002) "Which obstacles are most problematic for jumping horses?," *Applied Animal Behaviour Science*, 77(3), pp. 197–207. doi.org/10.1016/s0168-1591(02)00042-4.

Timney, B. and Keil, K. (1999) "Local and global stereopsis in the horse," *Vision Research*, 39(10), pp. 1861–1867. doi.org/10.1016/s0042-6989(98)00276-4.

Veilleux, C. C., and Kirk, E. C. (2014) "Visual acuity in mammals: effects of eye size and ecology", *Brain, behavior and evolution*, 83(1), pp. 43-53. doi.org/10.1159/000357830.

Wyszecki, G., Stiles, V.S. and Kelly, K.L. (1968) "*color science: Concepts and methods, quantitative data and formulas*," *Physics Today*, 21(6), pp. 83–84. doi.org/10.1063/1.3035025.