A retinoscopic survey of 333 horses and ponies in the UK

Albert Bracun, Andrea D Ellis, Carol Hall.*

School of Animal, Rural and Environmental Sciences, Nottingham Trent University, Southwell, Nottinghamshire, NG25 0QF, UK.

* Corresponding author: C. Hall
E-mail address: carol.hall@ntu.ac.uk
Telephone number: +44(0)1158485212

Running title: Retinoscopic survey of horses and ponies

Abstract

Introduction

Ophthalmic examination in the horse is generally limited to crude assessment of vision and screening for ocular lesions. The refractive state of equine eyes and the potential impact on vision and performance requires further investigation.

Objective:

To assess the refractive state of a large, mixed breed sample of horses and ponies in the United Kingdom (UK).

Procedure:

The refractive state of both eyes of 333 horses and ponies was determined by streak retinoscopy and the effect of age, height, gender, breed and management regime on the refractive state assessed.

Results:

The majority of eyes tested were emmetropic (83.63%), with 68.5% of horses having refractive errors of ≤ -0.50D or ≥ +0.50D. Refractive errors of greater than 1.50D (in either direction) were found in 2.7% of the eyes tested. Ametropic eyes included hyperopia (54%) and myopia (46%). Anisometropia was found in 30.3% of horses and ponies. Breed of horse / pony was the only factor that affected refractive state (in the left eye only, $p<0.05$) with

Thoroughbred crosses having a tendency towards myopia and Warmbloods / Shires towards hyperopia.

Discussion / Conclusion:

The retinoscopic survey found emmetropia to be the predominant refractive state of the equine eye with no evidence of an overall trend towards myopia or hyperopia. However, individual and breed related differences were found. Such factors should be considered in the selection of horses for sport and leisure, and when evaluating their performance potential. More comprehensive visual testing would be valuable in identifying underlying causes of behavioural problems.

Keywords: horse, vision, refractive state, emmetropia, myopia, hyperopia

Introduction

Veterinary ophthalmic examination in the horse is generally limited to a crude assessment of vision and screening for ocular lesions and does not often include determination of refractive state. Although the effect of refractive errors on vision and visual performance may be profound, the occurrence of refractive errors in equine eyes and the potential impact on performance warrants further investigation (1,2). Refractive state is defined as normal (emmetropic) when distant images are in focus on the photoreceptor layer in the absence of accommodation (3), which is only possible when the eyeball length is in proportion to the combined optical power (4,5). This relationship is particularly important in the horse, which has only limited dynamic accommodation (7). This ideal relationship is not innate (5,8), and in humans is the result of multiple factors including correct development during infancy (9,10), environmental factors (3,11,12,13,14) and genetic predisposition (15,16).

Refractive errors (ametropia) and the resultant blurred images occur when the focal point of an image is not on the retina but in front (myopia) or behind (hyperopia) it (17). Other refractive errors include presbyopia (from a change in lenticular elasticity) and astigmatism (generally from unevenly shaped cornea, lens or both) (17). In humans, refractive errors are common, with myopia occurring in 20 - 25% of the adult European population (18) and in up to 80% of some Asian populations (6,19). Contributing factors include ethnic origin, habitat (urban/rural), profession, and education (14). Variation within animal species has also been found, with refractive errors in dogs relating to both breed/skull morphology and to selection for performance (20,21). Amongst wild mammals the most common refractive state is a low degree of hyperopia (14,22).

The prevalence and type of refractive error occurring in equine eyes has received only limited investigation. Calculations of the normal equine refractive state on a schematic eye model resulted in a slightly hyperopic eye (+0.61D) (20). Harman *et al*. tested refractive error in 15 horses using retinoscopy and found most had no or only a small error with a tendency towards hyperopia which increased with age (23). In contrast, myopia was found in an early retinoscopic assessment of 100 equine eyes (24) , whilst with the same methodology two large scale studies involving 93 (25) and 150 horses (26) found emmetropia in 46% and 57% of their population respectively. Another study (n=117 horses) that included many foals, found 52% to be hyperopic (27). These studies (25,26,27) found an incidence rate of astigmatism in 23%, 6% and 15% respectively, whilst 43% of the eyes tested by Smith (24) were astigmatic. In a more recent study, Rull-Cotrina *et al*. compared the refractive state of Spanish Thoroughbred and crossbred horses and although the most prevalent refractive state was found to be emmetropia, there was a higher occurrence of myopia in the Thoroughbreds (28). Grinninger *et al.* also found a tendency to myopia with age in their retinoscopic evaluation of healthy equine eyes, with age-related changes occurring from the age of 7.5 years (29).

In the study by Rull-Cotrina *et al*. the administration of cyclopentolate ophthalmic solution in 18 of the horses was found to have no effect on retinscopy findings. (28). However, McMullen *et al.* found that topical application of tropicamide 1% resulted in blurry or reversing streak reflexes during subsequent streak retinoscopy (if maximal pupil dilation had not occurred) in almost half of the eyes tested (30). It was concluded that optimal streak retinoscopy results may be obtained prior to (or 40-45 minutes following) application of topical tropicamide 1% (30). No such treatment was used in the current study.

The potential impact of a refractive error on the horse's visual ability, performance and safety is unclear, but substantial refractive errors would be expected to have an adverse effect on these. The aim of this study was to conduct a survey of the refractive state of horses and ponies from a variety of disciplines within the UK using a large mixed breed sample.

Materials and methods

Subjects

Horses and ponies (n=375) kept at yards located in the Midlands area of the UK were initially assessed for inclusion in the study. The yards were selected by opportunistic sampling through local contacts within the equestrian industry. Written informed consent was obtained from owners of each horse used in the study (in accordance with the ethical review policy of Nottingham Trent University), in addition to details relating to age and management. Horses were not included in the study if they failed to stand still during the retinoscopic examination of one or both eyes (n=17). Horses (n=25) were also excluded from the study if the Purkinke-Sanson reflexes were not apparent and could not be be aligned with the retinoscope (due to repeated head movement by the horse / pony) (see below for details of this process). This resulted in the measurement of the refractive state of 333 horses and ponies (666 eyes), including 103 mares, 224 geldings and 6 stallions. Ages ranged from 1-27 years (mean age = 9.36 ±3.96 years). Breeds / type included Thoroughbred (n=85), Warmblood (n=26), Thoroughbred / Warmblood / other crosses (n=109), Cob (n=59), Shire (n=13) and other / unknown (n=41). Heights ranged from 132-180 cm (mean height = 161.49 ±7.79cm). The management regime of each animal was recorded (field, stable or combined stable/turnout).

Testing for refractive error

Each horse was brought into a darkened stable within its familiar environment and allowed to settle for a couple of minutes before the assessment. Streak retinoscopy was performed in horizontal and vertical meridians using a hand held streak retinoscope (Hamblin 832) and a trial lens set (with individual -ve/+ve lenses: 0.50, 1.0, 2.0, 3.0 and 4.0) with a working distance of 65 cm using the techniques described by Davidson (31) and Corboy (32). The movement of the central retinal reflex was judged against the one visible in the centre of the pupil, as described in detail by Corboy (32), with all examinations being carried out by the same examiner. The method was repeated in each eye and mean values were used in subsequent analyses.

All refractive assessments were performed without mydriasic / cycloplegic agents. The study was carried out in accordance with the Nottingham Trent University research ethics policy.

Data Collection and Analysis

Emmetropia was defined as a refractive state between -0.50 D and +0.50 diopters, (22) as in Chung *et al*. (18). Mean refractive error was calculated for each eye and any differences between the meridians noted. Refractive state of both eyes was recorded for each horse. The effect of the following factors on refractive state was assessed: age, height, gender, type and management regime.

Data analyses were conducted using IBM SPSS (19) statistics package and non-parametric analyses were used throughout (Kolmogorov Smirnov test). Prevalence of refractive errors was recorded, with differences between right and left eyes, and differences between vertical and horizontal meridians, tested using the Wilcoxon signed-ranks test for paired data. Correlations between age and wither height and refractive state were assessed (Spearman's Rank Order Correlation). The effect of gender, breed and management regime on refractive error was evaluated using the Kruskal-Wallis test, followed by pair-wise comparisons (Mann-Whitney U test). Values of $p<0.05$ were considered significant.

Results

Of the 333 horses tested 228 (68.5%) were found to have no refractive error in either eye. Of the 666 eyes tested 557 (83.63%) were emmetropic. Ametropia (refractive error ≤ -0.50D or ≥ +0.50D) occurred in the other 109 eyes and ranged from -5.00 to +5.00D. See Fig. 1. Eighteen (2.7%) eyes had a refractive error of greater than 1.50D (in either direction), which constitutes only 16.5% of all occurrences of ametropia. Of the 109 ametropic eyes 59 (8.86%) were hyperopic and 50 (7.51%) were myopic. Four horses (1.2%) were hyperopic in both eyes (+0.50 to +3.00D). No horses were found to be myopic in both eyes. Only four horses (1.2%) were found to have a refractive error of greater than 3 D (three were myopic and one hyperopic) and in each case this was in one eye only. These four horses were of varying height (149.86cm to 165.1cm) and type (as shown in Fig. 1, Table 1), consisted of three geldings and one mare, and were all 8 years or older (8, 9, 13 and 13). No other problems with their eyes or behaviour had been reported.

Anisometropia (where the refractive power of the two eyes differs by more than 0.5D) occurred in 101 (30.3%) horses. In 51 (15.3%) of the horses hyperopia was present in one eye (+0.50D to + 5.00D). In 50 (15.00%) of the horses myopia was present in one eye (-0.50D to -5.00D). When left and right eyes were considered separately it was found that 54 (16.22%) of the horses had refractive error in the left eye only (-5.00D to +4.00D) and 47 (14.11%) had refractive error in the right eye only (-4.50D to +5.00D). No horses with anisometropia were myopic or hyperopic in both eyes. No significant difference between left and right eyes was found.

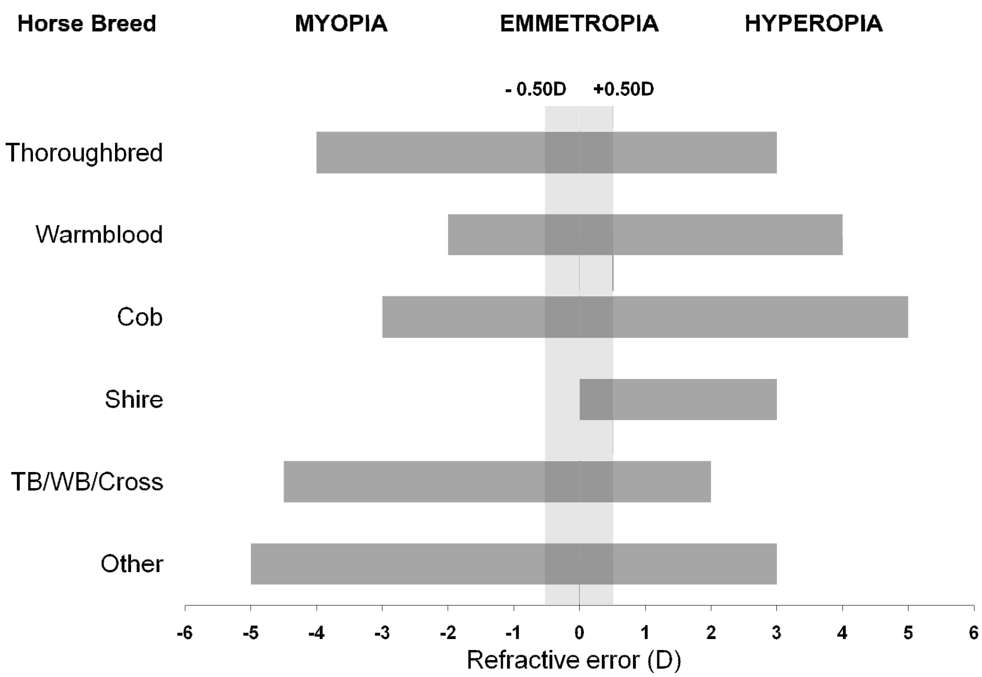


Figure 1: *Range of refractive errors found in different horse and pony breeds*

No significant difference in the refractive power of the vertical and horizontal meridians (astigmatism) was found. Differences in refractive error between the two meridians (vertical 90º and horizontal 180º) were found in six left eyes and five right eyes but these were all of 0.50D and the direction of the difference was not consistent.

No significant differences in refractive state were found in relation to gender or management style. There was however a significant effect of breed of horse on refractive state of the left eye only (Kruskal-Wallis test: χ^2 (5) = 11.197, p = 0.048). No significant effect of breed was found in the right eye (Kruskall-Wallis test: χ^2 (5) = 5.232, p = 0.388). The range of refractive error found in each breed / type of horse (both eyes combined) is shown in Fig. 1. Details of the range of refractive errors found in left and right eyes in relation to type, gender and age are shown in Table 1. Significant differences in refractive error were found between Thoroughbred crosses and Warmbloods (z=-2.763, p=0.006) and between Thoroughbred crosses and Shires (z=-2.247, p=0.025). There was a tendency towards hyperopia in Warmbloods and Shires, and towards myopia in Thoroughbred crosses.

No significant correlation between refractive error and height or age of horse was found.

Table 1: *Range of refractive state in relation to type, gender, age and height of horse. Where significant differences in refractive error were found between types (Mann-Whitney U test) this is shown as *p<0.05, **p<0.01.*

Breed / type	**Gender**	**Number of horses**	**% of sample**	**Age range (years)**	**Age mean (±SD)**	**Height range (+mean) cms**	**Refractive state (D)**			
							left min	**left max**	**right min**	**right max**
TB	♂*	2	0.6	12-12	12 (±0.0)	152-157 (155)	0	0	0	0
	♂	57	17.1	3-27	9.9 (±4.1)	152-173 (162.5)	-4	3	-0.75	1.125
	♀	26	7.8	3-25	9.4 (±5.4)	155-178 (162.5)	0	2	-1	1.625
TBx*,**	♂	23	6.9	3-25	10.0 (±4.7)	152-180 (160)	-1	2	-1.25	0.5
	♀	10	3.0	4-14	8.9 (±3.1)	150-162.5 (157.5)	-0.5	0.5	0	0
TBxWB	♂*	1	0.3	10	10.0 (±0.0)	157.5	0	0	0	0
	♂	37	11.1	2-21	9.6 (±3.4)	157.5-178 (165)	-2	1.5	-4.25	1.875
	♀	16	4.8	2-18	9.6 (±4.5)	157.5-175 (165)	0	0	-1.125	0.875
WB**	♂	18	5.4	3-15	9.2 (±3.8)	160-180 (170)	0	1.5	-1.875	0.5
	♀	8	2.4	3-14	9.5 (±3.3)	165-180 (172.5)	0	4	0	0
WBx	♂*	1	0.3	10	10.0 (±0.0)	162.5	0	0	0	0
	♂	12	3.6	5-14	10.2 (±2.8)	155-180 (165)	-1	0	-0.5	0
	♀	9	2.7	4-14	8.0 (±3.4)	157.5-175 (165)	0	0	0	1.125
Cob	♂*	2	0.6	4-7	5.5 (±2.1)	157.5-160 (157.5)	0	0	0	0
	♂	37	11.1	1-15	8.2 (±3.4)	150-165 (157.5)	-0.5	1.5	-3	0
	♀	20	6.0	5-21	10.1 (±4.2)	150-162.5 (157.5)	-0.5	2	-1.5	4.75
Shire*	♂	10	3.0	2-13	6.9 (±3.5)	167.5-178 (173)	0	0.5	0	2.75
	♀	3	0.9	7-12	9.7 (±2.5)	165-175 (170)	0	0	0	0
Other	♂	30	9.0	1-16	9.25 (±4.3)	132-173 (152.5)	-5	3	-1.625	3
	♀	11	3.3	5-16	9.15 (±2.5)	145-160 (152.5)	-1.5	1.5	-1.5	0.625
KEY	♂* =Stallion; TB= Thoroughbred; WB= Warmblood; x= Cross									

Discussion

The majority of eyes in this study were emmetropic (83.63%), with 68.5% of all horses tested having the no refractive error in either eye (within the >-0.50 and < +0.50D classification). Fewer refractive errors were found than in previous studies, although emmetropia was shown to predominate in all but the early study by Smith (24). Of previous work the closest to the findings of this study were those of Duval where 57% of the 300 eyes tested were found to be emmetropic (26) (see Fig. 2 for a comparative summary of the results of this and previous studies). When refractive errors occurred, in only 18 (2.7%) eyes were these greater than 1.50D although the range found (-5 to +5D) was greater than the -3 to + 3D reported to be typical of healthy horses (33). Of the four horses that were found to have a refractive error of greater than 3 D (three myopic and one hyperopic) this was in one eye only. Behavioural signs relating to lateral differences in visual ability (anisometropia) may well occur and visual testing for ametropia as well as for optical pathology is indicated. Unlike the findings of some previous studies [25,26,27,28] no significant astigmatism was found. This is comparable to the findings of Sivak and Allen who did not find refractive variation in a single eye of greater than 1.00D in any direction [7].

Age related changes in refractive error in the developmental stage are common in a number of species and are associated with the growth of the eyeball. Orbital shape influences eye morphology and refractive error relates to axial length (6). The tendency, in some species at least, is for animals to be born hyperopic with early age-related changes moving towards emmetropia (5). For example, Thomson gazelle (Gazella thomsoni) were found to be hyperopic at birth (approximately 3.44 ±0.31D) but by day 50 the animals were virtually emmetropic (22). This link between hyperopia and very young animals may in part explain the findings of Löf, whose sample of 117 horses included a large number of foals (youngest three days old). The results of Löf's study found 52% of the equine eyes tested were hyperopic and this was more common than emmetropia, with an estimate of the rate of emmetropization being measured as -0.60D a decade (27) (Fig. 2). In contrast, Harman et al. found a tendency towards increased hyperopia with age in horses (23), similar to human presbyopia (age related onset of hyperopia). No relationship between age and refractive state was found in the current study. Only seven animals under three years old were tested (three one-year-olds and four two-year-olds), five of which had no refractive error and two (two-year-olds) had refractive errors in one eye only of +0.50 and +3.00D respectively. No animals below the age of thirteen months were included in this study. In humans up to the age of six or seven years the normal refractive state is slightly hyperopic (0.40-1.00D), with adults (20 – 36 years of age) being on average a little myopic (-0.50D) (9). In humans axial length increases by 190.8%, from 12.5mm (25 week old baby) to 23.85mm in grown adults (34), whereas in horses it increases by only 128.8%, from 33.47mm to 43.1mm (35). A smaller axial length increase could be associated with a decreased variation of refractive errors, manifesting in more emmetropic individuals as found in the current study. Apart from soon after birth it appears unlikely that, in the majority of cases, the refractive state of equine eyes alters to any great extent throughout the life of the animal.

A relationship between refractive error and horse breed was found with the occurrence of hyperopia and myopia showing variation (see Table 1 and Fig. 1). Although no correlation between height and refractive error was found, the eyes of the Shire horses (height range approximately 170-180 cm) were all either emmetropic or hyperopic, with no instances of myopia. Breed variations in equine skull morphology have been linked with other visual characteristics such as retinal ganglion cell density, with longer heads positively correlating with increases in ganglion cell density in the visual streak (36). Inter breed differences in refractive state have been documented in dogs (21) and are influenced by skull morphology (37). Rull-Cotrina *et al.* found differences between Spanish Thoroughbred and crossbred horses, with the former showing a higher prevalence of myopia (28). In the current study the Thoroughbred cross horses also showed a higher prevalence of myopia than the Warmblood or Shire horses. Further investigation is required to determine the prevalence of breed-specific variation. Breed-related differences in visual ability may affect performance. For example, in the study by Östberg dressage horses were more likely to have myopia than those competing in other disciplines (25). In human studies profession was one factor found to influence the occurrence and nature of refractive errors (14). Whether the type of training used for dressage horses (as opposed to show jumpers, racehorses and other disciplines) has increased this tendency, as noted in dogs trained for a specific purpose (21), or whether this is related to breed, trait selection, management style or a combination of factors, is unclear.

Despite the use of the same methodology within this and the other large scale studies, there is considerable variation in the findings (see Fig 2). Most notable is the study by Smith who found the most common refractive state to be myopic, with a mean value of just under -1.00D (24). However the normally fixed working distance in this study was variable (described as: “standing at a minimum distance of four feet” (24), 1.22m). This apparently variable working distance and the fact that the working distance has been factored with 1.00D rather than

0.82D distort the normal distribution curve (Fig. 2). Re-evaluation of the data with the "correct" working distance (Fig. 2: Smith (1894)*) results in a less myopic refractive state with a mean of -0.78D. Even with this re-evaluation only one horse (2%) is in the low hyperopic field outside the emmetropic bracket.

The variation in the results of the large scale studies could also be attributed to the effects of different management techniques in early life that affect the refractive state. The visual environment has been shown to influence refractive state by controlling changes in the axial length of the eye during the postnatal developmental period in a number of species (38). It has been demonstrated that deprivation of distant vision during a critical development time for the eye, increases myopia in adulthood (11,12). In horses such restriction could be caused by the lack of distant visual clues in stables, especially influencing the ocular development of foals born and stable kept for the first months of their life. Thoroughbred foals are often stabled in order to be safeguarded from the cold temperatures around their intended birth date (as soon after 1st January as possible). Both Östberg and Rull-Cotrina *et al*. found myopia to be particularly prevalent in Thoroughbreds (25,28), although the same was not found in the current study. This is possibly the consequence of having a large number of thoroughbreds with a non-racing background in the sample and/or international differences in horse husbandry.

Equines have small variations from the nodal point to the retina (23) making an identification of the exact measurement location essential, without which measurement differences of up to 0.75D within the same subject are possible (7). In the current study each eye was measured twice in each of the main meridians and to maximise the accuracy of each measurement, refractive assessments were performed as close as possible to the optical axis. This was located by ensuring the Purkinje-Sanson reflexes were in the centre of the pupil and overlaying each other (31,32). A variation between the measurements occurred in one fifth (20.42%) of the horses and was nearly exclusively of 0.50D nature.

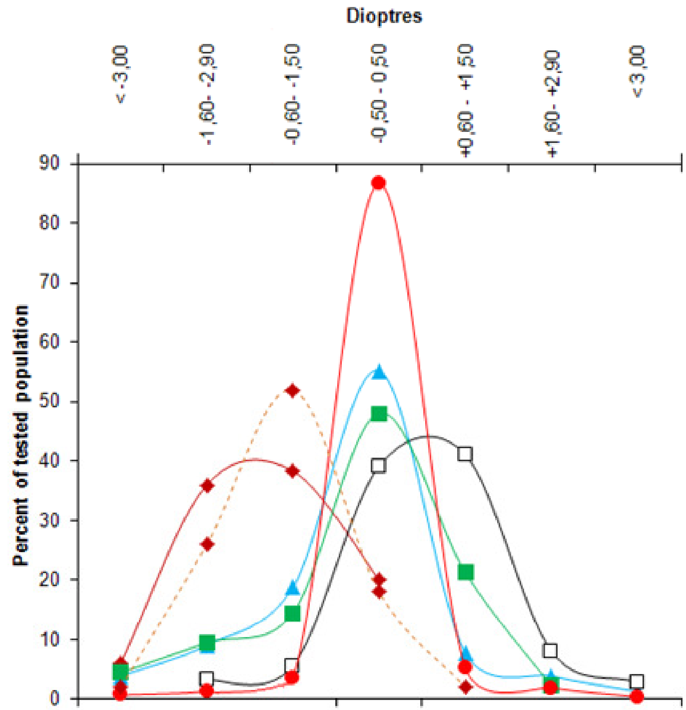
In many species active accommodation may influence refraction results (39) and cycloplegic agents are required (40). Horses have a normal accommodative ability of around 2D, which falls within the range of the remaining accommodative ability of 1.00 to 2.50D after cycloplegic instillation with the most powerful drug (4). Although Löf found a significant difference between the refractive assessment of young foals (3 to 37 days old) with and without cycloplegia, no difference in the measurements of yearlings (9 to 14 months old) was found (27). No differences were found by Rull-Cotrina *et al*. (28). McMullen *et al.* found that

1% tropicamide induced mydriasis and cycloplegia could make retinoscopy results less accurate unless a period of 40-45 minutes was allowed to ensure maximal pupil dilation and that optimal streak retinoscopy results could be obtained prior to this administration (30). In the light of previous findings [4,28], and as the youngest horse in the current study was over 12 months old, it was not considered necessary to use cycloplegia in this study.

The refractive state of the eye will determine visual ability, in particular visual acuity. In horses the greatest density of cone photoreceptors and retinal ganglion cells occur in the temporal area of the visual streak and the visual axis extends from the centre of the pupil to this area (41). In humans the optical and visual axes vary only minimally, with the visual axis ending at the fovea and the optical axis ending at a point between the optic disc and the fovea centralis (42). However, when interpreting the results of retinoscopy in terms of visual ability, the potential effect of the discrepancy between the optical and visual axes should be taken into account.

The visual ability of the horse and consequently its performance and behaviour will depend in part on its ability to form an in-focus image on the retina of objects at varying distances. The results of the current survey indicate that emmetropia predominates and no evidence was found to suggest that there was a trend towards myopia or hyperopia, or age related changes. Lateral differences in the occurrence of refractive errors were found in individual horses and these may result in behavioural anomalies. Further work is required to determine the overall effect of refractive errors on visual ability, but it is suggested that more comprehensive visual testing would be valuable in determining performance potential and in identifying underlying causes of behavioural problems.

Acknowledgements: We would like to thank the horse and pony owners for allowing their animals to be used in this study.



Study	Number of Eyes	Myopia %	Emmetropia**	Hyperopia %
Smith (1894)	100	80	20	0
Smith (1894)*	100	80	18	2
Duval (1976)	300	33	57	13
Löf (2007)	234	9	39	52
Ostberg (2007)	186	27	46	23
This study	666	8	84	9

* data has been rectified by 0.20D to account for wrong working distance
** interval for Emmetropia is between -0.50D and 0.50D

Figure 2: *Comparative distribution of refractive state found by retinoscopic examination of horses and ponies in the current and previous large scale studies of equine eyes. The associated percentages of refractive errors found are included.*

References

1. Murphy J, Hall CA, Arkins S. What horses and humans see: A comparative review. *International Journal of Zoology* 2009; doi: 10.1155/2009/721798 (available online).
2. Miller PE, Murphy CJ. Equine Vision: Normal and Abnormal. In: *Equine Ophthalmology* (ed. Gilger BC). Elsevier and Saunders Ltd.: St Louis, Missouri, 2005; 371-408.
3. Mutti DO, Zadnik K, Adams AJ. Myopia: the nature versus nurture debate goes on. *Investigative Ophthalmology and Visual Science* 1996; 37: 952-957.
4. Zadnik R. *The Ocular Examination: Measurements and Findings*. W.B. Saunders, UK, 1997.
5. Howlett MHC, McFadden SA. Emmetropization and schematic eye models in developing pigmented guinea pigs. *Vision Research* 2006; 47: 1178-1190.
6. Wright KW. *Pediatric Ophthalmology for Primary Care*. 3rd edition. American Academy of Pediatrics, 2008.
7. Sivak JG, Allen OB. An evaluation of the "ramp" retina of the horse eye. *Vision Research* 1975; 15: 1353-1356.
8. Graham B, Judge S J. Normal development of refractive state and ocular component dimensions in the marmoset (*Callithrix jacchus*). *Vision Research* 1999; 39: 177-187.
9. Gordon RA, Donzis PB. Refractive development of the human eye. *Archives of Ophthalmology* 1985; 103: 785–789.
10. McClatchey SK, Dahan E, Maselli E, *et al*. A comparison of the rate of refractive growth in pediatric aphakic and pseudophakic eyes. *Ophthalmology* 2000; 107: 118-122.
11. Young FA. The effect of restricted visual space on the refractive error of the young monkey eye. *Investigative Ophthalmol*ogy 1963; 2: 571-577.
12. Rose L, Yinon U, Belkin M. Myopia induced in cats deprived of distance vision during development. *Vision Research* 1974; 14: 1029-1032.
13. Kinney JA, Luria SM, Ryan AP, *et al*. The vision of submariners and National Guardsmen: A longitudinal study. *American Journal of Optometry and Physiological Optics* 1980; 57: 469-78.
14. Rosenfield, M. and Gilmartin, B. *Myopia and Nearwork*. Butterworth and Heinemann, Oxford, 1998.
15. Flitcroft DI. A model of the contribution of oculomotor and optical factors to emmetropization and myopia. *Vision Research* 1998; 38: 2869-2879.
16. Young TL, Ronan SM, Alvear AB. A second locus for familial high myopia maps to chromosome 12q. *American Journal of Human Genetics* 1998; 63: 1419–1424.
17. Sekuler R, Blake R. *Perception.* 5th edition. McGraw-Hill International, Singapore, 2006.
18. Chung K, Mohidin N, O'Leary DJ. (2002) Undercorrection of myopia enhances rather than inhibits myopia progression. *Vision Research* 2002; 42: 2555-2559.
19. Wong TY, Klein BE, Klein R, *et al.* Refractive errors, intraocular pressure, and glaucoma in a white population. *Ophthalmology* 2003; 110: 211-217.
20. Coile DC, O'Keefe LP. Schematic eyes for domestic animals. *Ophthalmic and Physiological Optics.* 1988; 8: 215-220.
21. Murphy CJ, Zadnik K, Mannis MJ. Myopia and refractive error in dogs. *Investigative Ophthalmology and Visual Science* 1992; 33: 2459-2463.
22. Ofri R, Millodot S, Tadmor Y, *et al*. The development of the refractive state in the newborn Thomson gazelle. *Journal of Comparative Physiology A: Neuroethology, Sensory, Neural, and Behavioral Physiology* 2004; 190: 831-835.
23. Harman AM, Moore S, Hoskins R *et al*. Horse vision and an explanation for the visual behaviour originally explained by the "ramp retina". *Equine Veterinary Journal* 1999; 31: 384-390.

24. Smith F. The Refractive Character of the Eyes of Horses. *Proceedings of the Royal Society of London* 1894; 55: 414-422.
25. Östberg S. *Undersökning av ögats brytningsförmåga i ett svenskt hästmaterial (Examination of the refractive error in Swedish horses).* Veterinary Thesis, Uppsala, 2007.
26. Duval M. Contribution a l'etude du globe oculaire chez le cheval par la skiascopie et l'echographie. *Xavier Woimant* 1976; 69: 20-21.
27. Löf A. *Undersökning av ackommodationsförmåga och brytningsfel hos varmblodiga travare (Investigation into the accomodative capabilities and astigmatism of the warm blood trotter).* Veterinary Thesis, Uppsala, 2007.
28. Rull-Cotrina J, Molleda JM, Gallardo J, *et al*. Refractive state of the Spanish Thoroughbred horse: a comparison with the crossbred horse. *Veterinary Ophthalmology* 2013; 16: 25-28.
29.Grinninger P, Skalicky M, Nell B. Evaluation of healthy equine eyes by use of retinoscopy, keratometry and ultrasonographic biometry. *American Journal of Veterinary Research* 2010; 71: 677-681.
30. McMullen RJ, Davidson MG, Gilger BC. The effect of 1% tropicamide-induced mydriasis and cycloplegia on spherical refraction of the adult horse. *Veterinary Ophthalmology* 2013; doi: 10-1111/vop,12055.
31. Davidson MG. Clinical retinoscopy for the veterinary ophthalmologist. *Veterinary Comparative Ophthalmology* 1997; 7: 128-137.
32. Corboy JM. *The Retinoscopy Book: An Introductory Manual for Eye Care Professionals*. Thorofare: Slack Incorporated, 1996.
33. Michau TM. Equine ocular examination: Basic and advanced diagnostic techniques. In: *Equine Ophthalmology* (ed. Gilger BC). Elsevier and Saunders Ltd.: St Louis, Missouri, 2005; 1-62.
34. Weale RA. Epidemiology of refractive errors and presbyopia. *Survey of Ophthalmology* 2003; 48: 5.
35. Svaldenienė E, Paunksnienė M, Babrauskienė V. Ultrasonographic study of equine eyes. *Ultragarsas* 2004; 4: 49-51.
36. Evans KE, McGreevy PD. The distribution of ganglion cells in the equine retina and its relationship to skull morphology. *Anatomia, Histologia, Embryologia* 2007; 36: 151-156.
37. Gaiddon J, Bouhana N, Lallement PE. Refraction by retinoscopy of normal, aphakic and pseudophakic canine eyes: Advantage of a 41-Diopter intraocular lens? *Veterinary Comparative Ophthalmology* 1996; 6: 121-124.
38. Norton TT. Animal models of myopia: learning how vision controls the size of the eye. *Institute for Laboratory Animal Research Journal* 1999; 40: 59-77.
39. Owens DA. A comparison of accommodative responses and contrast sensitivity for sinusoidal gratings. *Vision Research* 1980; 20: 159.
40. Saunders KJ, Woodhouse JM, Westall CA. Emmetropisation in human infancy: rate of change is related to initial refractive error. *Vision Research* 1995; 35: 1325-1328.
41. Timney B, Keil K. Visual acuity in the horse. *Vision Research* 1992; 32: 2289-2293.
42. Girod B. *Human visual perception*. EE368b Image and Video Compression, Stanford University, 2009.