Title

The effect of age on binocular vision normative values

Author

	Last Name	First Name	Academic Degree
1	Sánchez-González	María Carmen [a]	OD, PhD
2	Sánchez-González	José-María [a]	OD, PhD
3	De-Hita-Cantalejo	Concepción [a]	OD, PhD
4	Vega-Holm	Margarita [b]	PhD
5	Jiménez-Rejano	José-Jesús [c]	PhD
6	Gutiérrez-Sánchez	Estanislao [d]	MD, PhD

[a] Department of Physics of Condensed Matter, Optics Area, University of Seville, Reina Mercedes S/N, Seville, Spain

[b] Department of Organic and Medicinal Chemistry, Faculty of Pharmacy, University of Seville, Professor García González 2, 41012 Seville, Spain

[c] Physiotherapy Department, Faculty of Nursing, Physiotherapy and Podiatry, University of Seville, C/ Avicena S/N, 41009 Seville, Spain

[d] Department of Surgery, Ophthalmology Area, University of Seville, Doctor Fedriani S/N, 41009, Seville, Spain

Corresponding author:

Name: Sánchez-González, María Carmen, OD, PhD, University of Seville

Address: Reina Mercedes St. Physic Faculty, University of Seville, Seville, Spain.

Telephone number: +34 649532854

E-mail address: msanchez77@us.es

Abstract

Purpose: Establish relationship between age and horizontal heterophoria, horizontal fusional vergence amplitudes and vergence facility testing.

Methods: The sample consisted of 112 subjects with a mean age of 39.8 years (standard deviation [SD], 14.97; range, 18.0-65.0 years) and was composed of 61 (54.5%) women and 51 (45.5%) men. Non presbyopic group included subjects aged 18 to 39 years (n=49) and presbyopic group, 41 to 65 years (n=63). Binocular vision was studied by heterophoria horizontal magnitude (prism diopters, Δ), horizontal fusional vergences amplitudes (Δ), and vergence facility testing (cycles per minute [cpm]) and quantified with a prismatic combination 3 Δ base-in/12 Δ base-out.

Results: Significant differences were obtained in near heterophoria with compensation (increased of 3.74Δ exophoria [X], t = 2.12, $P < .05$), recovery distance positive fusional vergence (PFV) (decreased of 2.86 Δ, t = 3.03, $P < .01$), blur near PFV (decreased of 3.13 Δ, t = 1.98, $P = .05$), break near PFV (decreased of 4.45 Δ, t = 2.75, $P < .01$), recovery near PFV (decreased of 4.69 Δ, t = 3.30, $P < .01$) and vergence facility testing (decreased of 2.63 Δ, t = 2.77, $P < .01$).

Conclusions: Our results indicated an increase of exophoria and a decrease in near positive horizontal fusional vergences and vergence facility dependent on age; thus, we suggest that changes in the normal values should be considered for each age range.

Keywords

presbyopia; vision disorders; horizontal fusional vergences; vergence facility

INTRODUCTION

Binocular vision is obtained with the simultaneous use of both eyes and the fusion, at the level of the brain, of their respective images. To achieve this, the eyes must be correctly aligned on a fixation point, whereby bifoveal fixation occurs by stimulating the corresponding retinal spots in both retinas.[1] To ensure binocular vision, fusional vergences compensate for heterophoria[2] to ultimately achieve a single binocular vision image and avoid diplopia.[3]

The eyes move via the extraocular muscles, and the movements that allow for correct aiming and are responsible for binocular vision are called vergencial movements. They are divided into four components: tonic vergence, accommodative vergence, proximal vergence, and fusional vergence.[4] In addition, in the evaluation of fusional vergence, a range of outcomes is determined by the following: blur, which measures the amount of merge fusion free of accommodation; break, which indicates the amount of fusional vergence and accommodative vergence; and recovery, which measures the patient's ability to recover binocular vision after diplopia.[3]

Nonstrabismic binocular dysfunctions are vision disorders that affect the binocular system and visual performance of the subjects. These dysfunctions tend to cause difficulties in activities related to near vision and induce symptoms such as blurred vision, difficulty reading, headache, diplopia, and, in many cases, inability to maintain comfortable viewing for a long time.[5,6]In recent decades, the prevalence of these dysfunctions has been signally increased.[7,8] Montés-Micó[9] found 56.2% of subjects presented with symptoms of binocular dysfunction, 61.4% with accommodative disorders and 38.6% with vergence disorders. The study population were from an ophthalmologic clinic. Several symptoms and signs can be used to diagnose these dysfunctions. However, there is a lack of consensus among researchers about which diagnostic criteria are useful for defining each anomaly [10,11] The clinical signs are the objective manifestations observed in ophthalmic and optometric examination and are considered in or out of normative values. The most commonly used normative values were established by Morgan [12] and Scheiman and Wick.[13] In their publications, these authors referred to both children and adults, but they did not specify the ages of the subjects within the adult population.

Scientific literature supports that, with age, a decrease occurs in visual acuity, contrast sensitivity, stereoacuity [14-18] and accommodation.[19] Accommodation is a physiological process. When a change occurs in lens shape, it increases or decreases the diopter power of the eye and produces a clear image on the retina of objects located at different distances.[20] Loss of accommodation begins in adolescence. Children have an accommodation amplitude (AA) up to 15 diopters (D), in adolescents it is still about 10 D [8] in the second and third decades of life, the decrease in accommodation accelerates. At this moment, the accommodative reserve is insufficient, and there are difficulties in carrying out the tasks in the near vision. From 50 – 55 years, the accommodative capacity is completely stopped.[19,20] This implies changes in the global vergence system that affect the ability to maintaining binocular vision[4,21]. Ciliary muscle, responsible for accommodation, and extraocular musculature, responsible for convergence, present same innervation. Convergence stimulates accommodation and divergence relaxes it. [22,23]

Both systems, accommodative and vergencial, work together to maintain stable vision. The relationship between the two systems is given through AC/A (change in convergence caused by a certain change in accommodation) and CA/C (change in accommodation induced by a change in convergence).[24] Other authors found an increase of exophoria [25,26] in presbyopic population. This situation rises patient-referred symptomatology. Visual therapy has been described as a treatment option in adults with decompensated heterophoria. [27,28]

The objective of our study is establishing relationships between subject age and the values of these variables; horizontal heterophoria, [25,26] range of horizontal vergences, base-in (BI) or negative fusional vergence (NFV), base-out (BO) or positive fusional vergence (PFV) and vergence facility (VF) testing, [29,30] is designed to assess the dynamics of the fusional vergence system and the ability to respond over a period of time.

PATIENTS AND METHODS

Design

This observational, prospective, cross-sectional, correlational study was conducted from March 1, 2017, to December 31, 2017, at the Faculty of Pharmacy, Optics and Optometry Titling facilities of the University of Seville, Spain.

Ethics

The research followed the tenets of the Declaration of Helsinki. Informed consent was obtained from the subjects after explaining the nature and possible consequences of the study, and the Institutional Review Board (HVM) approved the research.

Subjects

The selected population was composed of students, professors, and administrative and service personnel of the University of Seville. A recruitment letter was sent via email to the entire university community (143 subjects) of the Faculty of Pharmacy at the University of Seville. All subjects were informed verbally and in writing. 6 people refused to participate and 3 did not sign the informed consent, leaving a total of 134 participants who gave their consent to participate in this research.

Questions included were: (1) Have you had any history of previous ocular pathology? (2) Did you use glasses or contact lenses during infancy? (3) Have you been involved in any type of eye surgery? (4) Have you a history of ocular pathologies in your family? (5) Do you currently suffer from any type of disease at all? (6) Do you take medication? If yes, describe in detail. In the face of suspicion of a possible alteration of the anterior segment, a screening corneal topography was carried out. 22 were excluded (Figure 1) due to not meeting the inclusion criteria for the study.

Measurements and procedures

Horizontal Heterophoria

The magnitude of the horizontal heterophoria (prism diopters, Δ) was performed at distance and near (6 m and 0.4 m) with an occluder, a prism bar, and a near accommodative target using alternating prism cover test. [31,32]

Horizontal Fusional Vergences

Horizontal fusional vergences (Δ), in both directions base-in (BI) or negative (NFV) and base-out (BO) or positive (PFV), were measured using the rotary prisms of the phoropter (Essilor, France). The two methods used (rotary prism in the phoropter and prism bars) to measure fusional vergences showed fairly good inter-session repeatability for measuring NFV but repeatability was reduced for PFV measurements.[3] A 20/30 Snellen letter was used as a fixation target in the distance.[33] (with both eyes, Snellen scale). It was projected to 6 m to obtain far values. The near vergences was tested with standard fixation card mounted in a phoropter at 0.4 m.[3,29] The patients fixated on a letter (either far or near). Licensed and expertise optometrist performed all optometric examinations. Prisms were introduced at a rate of 1 Δ per second. The patient indicated when he or she saw the text blurred (blur point) or doubled (break point). Patients were instructed to report when they clarified the image. The prismatic power was then decreased until the patient merged the image again (recovery point). NFV was measured with the BI prism and the PFV was measured with BO prism. For the NFV distance, there was no blur point.[3] First, vergence range was determined first at distance fixation, then for near fixation. NFV was always measured first, because there seems to be a prismatic adaptation if PFV are measured first.[34]

Vergence facility (VF) testing

VF testing (cpm) was quantified with a prismatic combination 3 Δ BI/12 Δ BO. Repeatability of test results was good at near.[35] VF was measured by changing between BI and BO prisms (first BI) with a prism flipper, requiring the subjects to converge and diverge. Encouragement was done especially when assessing convergence fusional amplitudes. The fixation point was a near Snellen chart located 0.4 m from the subject. It presented a visual acuity (VA) equivalent of 20/30 (with both eyes, Snellen scale). The measurement involved introducing the BI first. The patient clarified the image. Next, we changed to BO. The process alternated for 1 minute. The number of complete cycles (one BI and one BO prism) was the value of the VF.[35]

Data Analysis

Data were analyzed using the SPSS 24 package for Windows (SPSS Science, Chicago, IL). The normality of variables was verified using the Shapiro -Wilk test. Next, the relationship between the variables (distance horizontal heterophoria without compensation, distance horizontal heterophoria with compensation, near horizontal heterophoria without compensation, near horizontal heterophoria with compensation, distance break BI or NFV, distance recovery BI or NFV, near blur BI or NFV, near break BI or NFV, near recovery BI or NFV, distance blur BO or PFV, distance break BO or PFV, distance recovery BO or PFV, near blur BO or PFV, near break BO or PFV, near recovery BO or PFV and vergence facility testing (VF) and age was studied, calculating the Pearson coefficient R and carrying out a simple linear regression analysis, showing the values of the coefficient of determination R^2 and unstandardized coefficient b. The values of binocular vision were compared in the groups in which we differentiated the subjects according to the age ranges. Student t test was used. Effect size was calculated with partial square eta coefficient and Cohen's d. Finally, subjects were classified in and out the norm, distance and near PFV were classified by Morgan [12] (it was based on a study with 800 subjects in which it valued the heterophoria, next point of convergence and positive and negative fusional vergences), horizontal heterophoria (HH) and VF were classified by Scheiman & Wick [13] (to our knowledge, they were first one to establish these normative values), and compared between non presbyopic and presbyopic groups, using Chi Square test. All statistical tests were performed with 95% confidence level ($P < .05$).

RESULTS

The sample consisted of 112 subjects with a mean age of 39.8 years (standard deviation [SD], 14.97; range, 18.0-65.0 years) and was composed of 61 (54.5%) women and 51 (45.5%) men. Non presbyopic group included subjects aged 18 to 39 years (n=49) and presbyopic group, 40 to 65 years (n=63). All subjects had at least 20/20 visual acuity (in both eyes, Snellen scale) with their best correction in distance and near. Correction was considered in near to all participants. Room illumination was 120 cd/m^2.[36] All subjects had absence of ocular motility defects, manifest strabismus, nystagmus, corneal ectasias, suppression, diplopia or amblyopia (VA under 20/25 in both eyes, Snellen scale), and any ocular or systemic disease that could affect the results. We carried out a questionnaire that reported subject's ocular status.

Relationship between horizontal phoria and vergence system versus age

We studied the horizontal phoria at distance and near fixation, negative, and positive vergences both in far and near and vergence facility compared by age. Age have been treated as a continuous and quantitative variable in correlation study. A statistically significant relationship was obtained between age and the variables listed in Table 1. Linear regression models are also shown in Figure 2.

Comparison of presbyopic group vs. non presbyopic group

A comparison was then made of all study variables according to the defined non presbyopic and presbyopic groups. Significant differences were obtained in near heterophoria with compensation (3.15 ± 8.90 X and 6.87 ± 6.76 X, $P < .05$), recovery distance PFV (10.35 ± 5.29 Δ and 7.48 ± 4.35 Δ, P < .01), blur near PFV (14.21 ± 7.30 Δ and 11.08 ± 6.40 Δ, $P < .05$), break near PFV (22.12 ± 8.70 Δ and 17.67 ± 7.77 Δ, $P < .01$), recovery near PFV (14.24 ± 7.80 Δ and 9.55 ± 6.71, $P < .01$) and vergence facility (10.70 ± 4.96 cpm and 8.07 ± 3.41 cpm, $P < .01$). A statistically significant relationship (t-student test) between the six variables was found between non presbyopic group (18-39 years) and presbyopic group (40-65 years). Results are shown in Table

2 The boxplot graphs for near heterophoria with compensation, recovery distance PFV, near PFV (blur, break and recovery) and vergence facility are represented in Figure 3.

For the statistically significant variables, the size of the effect was calculated. For near heterophoria with compensation an effect size of 0.48, which was considered a medium-sized effect. The mean difference was 3.74 Δ, with a confidence interval of [0.86 – 7.40]. Recovery distance PFV an effect size of 0.59, which was considered a medium-sized effect. The mean difference was 2.86 Δ, with a confidence interval of [1.01 - 4.71]. Blur near PFV an effect size of 0.45, which was considered a medium-size effect. The mean difference was 3.13 Δ, with a confidence interval of [0.08 - 6.18]. Break near PFV an effect size of 0.54, which was considered a medium-size effect. The mean difference was 4.45 Δ, with a confidence interval of [1.32 - 7.58]. Recovery near PFV an effect size of 0.64, which was considered a medium-size effect. The mean difference was 4.69 Δ, with a confidence interval of [1.93 – 7.45] and vergence facility an effect size of 0.61, which was considered a medium-size effect. The mean difference was 2.63 cpm, with a confidence interval of [0.81 – 4.45] Linear regression along with the trendline are represented for distance recovery NFV, distance recovery PFV, blur, break, and recovery in near PFV and vergence facility versus age in Figure 2.

Classification according to the normative values of Morgan and Scheiman & Wick

The values of the near PFV were classified according the normative values established by Morgan[12], and vergence facility was classified according to the normative values established by Scheiman and Wick.[13] We compared these values between non presbyopic and presbyopic groups. For the variable recovery distance PFV, 12.2% non presbyopic subjects had values below the norm, whereas 24.1% presbyopic subjects had values below the norm. It was also found that in non presbyopic group, 20.4% had value above the norm; in presbyopic group, the percentage was 6.9% ($\chi 2 = 5.57$, $P = .05$). Blur for near PFV, 42.9% subjects in non presbyopic group had values below the norm, whereas for presbyopic group, the percentage amounted to 51.3%. It was also found that in non presbyopic group, 16.7% of subjects had values above the norm; in presbyopic group, this percentage was 5.1% (χ^2 = 2.77, *P* = 0.25). For the variable break in near PFV, we found that in non presbyopic group, 24.5% of subjects had values below the norm; however, the percentage in presbyopic group was 43.3%. In non presbyopic group, 30.6% of subjects had values above the norm, whereas for presbyopic group, the percentage was 13.3% (χ^2 = 6.57, *P* = .03). For the variable recovery in near PFV, we found that in non presbyopic group, 2.0% of subjects had values below the norm, whereas the percentage in presbyopic group was 15.0%. In non presbyopic group, 26.5% subjects had values above the norm, and for presbyopic group, the percentage was 6.7% (χ^2 = 11.93, *P* = .03). Vergence facility was the last variable that showed a significant difference between groups; we observed that in non presbyopic group, 65.9% of subjects had values below the norm, whereas the percentage in presbyopic group was 86.0%. In non presbyopic group, 9.1% of subjects had values above the norm, whereas presbyopic group did not have any patients with values above the norm (χ^2 = 6.43, *P* = .04).

DISCUSSION

In this study, we proposed an evaluation of horizontal heterophoria, range of horizontal vergences, BI or NFV, BO or PFV and VF testing that define the state of binocular vision in a sample with two age intervals (non presbyopic group and presbyopic group), using tests that that present the highest repeatability to establish relationships between age and binocular vision variables. Results matched with previous studies, which indicate how age affects the binocular vision variables.[37-39] Palomo et al. established a relationship between age and binocular vision only at distance fixation.[38] Other authors, have measured binocular vision values individually.[4,39] In addition, normative values described were referred to adult population without specifying age ranges.[12,40]

Our analysis indicated that the values of near horizontal heterophoria with compensation, distance recovery PFV, blur, break and recovery PFV in near and VF which determine the status of binocular vision, decrease with age. The results obtained for the statistically significant variables were analyzed according to the normative values in adults. According to the normative values of Scheiman and Wick [40] near horizontal heterophoria (HH) with compensation standard range 3 exophoria (X) ± 3 Δ. Non presbyopic group obtained 3.15 X Δ and presbyopic group obtained 6.87 X Δ. Presbyopic group was clearly found to be outside the norm. According to the normative values of Morgan [12] (horizontal fusion vergences), distance recovery PFV standard ranges from 6 to 14 Δ. Non presbyopic group obtained 10.35 ± 5.39 Δ and presbyopic group obtained 7.48 ± 4.35 Δ. Presbyopic group was clearly found to be outside the norm. Near blur PFV standard ranges from 12 to 22 Δ. Non presbyopic group obtained 14.21 ± 7.30 Δ and presbyopic group obtained 11.08 ± 6.40 Δ. Presbyopic group was found to be outside the norm. Near break PFV normative value ranges from 15 to 27 Δ. Non presbyopic group obtained 22.12 ± 8.70 Δ and presbyopic group obtained 17.67 ± 7.77 Δ. The normative value of near recovery PFV ranges from 4 to 18 Δ. Non presbyopic group obtained 14.24 ± 7.80 Δ and presbyopic group obtained 9.55 ± 6.71 Δ. Although presbyopic group is within the standard, the difference between groups is notable.

Finally, the VF normative value is 15 ± 3 cycles per minute (cpm) per Scheiman and Wick, as Morgan did not include it in his study. For this variable, non presbyopic group obtained 10.70 ± 4.96 Δ and presbyopic group obtained 8.07 ± 3.41 Δ. Therefore, in presbyopic group, no patient was within the standard for the VF values.

Stable vision maintenance required collaboration of accommodative and vergencial systems.[24] The AC/A ratio not has been studied because of the age of the subjects (18 to 65 years). In this sense, negative lens used in AC/A measurement, stimulates accommodation. Presbyopes patients do not have accommodation to clarify the text under this situation. For this reason, the variable was not studied. With age, a decrease in accommodation occurs [19] which produces an increase in the AC/A ratio and a decrease in the CA/C ratio. Near objects are blurred by a decrease in accommodation amplitude.[37,41,42] These changes imply rearrangements in the other components of vergence, in order to achieve a unique and stable binocular vision.[4]

Most studies conclude that there is no evidence of change either in proximal vergence or tonic vergence that is able to counteract the increase in accommodative convergence.[37] Therefore, it must be the fusional convergence that varies. As shown in our results, near HH with compensation increase of 3.74 X Δ, recovery distance PFV decreased of 2.86 Δ, blur near PFV decreased of 3.13 Δ, break near PFV decreased of 4.45 Δ, recovery near PFV decreased of 4.69 Δ and VF decreased of 2.63 Δ. Most of variables correspond to the value of the near PFV, which is directly related to accommodation.

In exophoria, visual axes tend to go outward without manifesting deviation, since fusion mechanism (PFV) is responsible for coordination at a fixation point. Convergence-accommodation mechanism relaxation suppose that visual axes divergence. Hence, with age, increases near exophoria value,[25,26] due to convergence-accommodation mechanism inefficiency. We also observed a decrease in VF associated with age, a result that is in line with other study.[39] In addition, this result is justified, because vergence facility evaluates the dynamic ability of the fusional vergence system [35] in other words, the subject's ability to merge images.

In conclusion, our results indicated an increase of exophoria and a decrease in near positive horizontal fusional vergences and VF through age. Thus, we believe that normative values defined for the entire adult population should not be generalized. They must be interpreted according to patient age, because accommodation in a young population is not equal to that of presbyopes. Changes in the normal values should be considered for each age range. We suggest that by increasing the population under study, a normative value in relation to age can be established.

References

1. Hillis JM, Banks MS. Are corresponding points fixed? *Vision Res*. 2001;41(19):2457-2473.
2. Conway ML, Thomas J, Subramanian A. Is the aligning prism measured with the Mallett unit correlated with fusional vergence reserves? Bui B V., ed. *PLoS One*. 2012;7(8):e42832. doi:10.1371/journal.pone.0042832
3. Antona B, Barrio A, Barra F, Gonzalez E, Sanchez I. Repeatability and agreement in the measurement of horizontal fusional vergences. *Ophthalmic Physiol Opt*. 2008;28(5):475-491. doi:10.1111/j.1475-1313.2008.00583.x
4. Baker FJ, Gilmartin B. A longitudinal study of vergence adaptation in incipient presbyopia. *Ophthalmic Physiol Opt*. 2003;23(6):507-511.
5. García-Muñoz Á, Carbonell-Bonete S, Cacho-Martínez P. Symptomatology associated with accommodative and binocular vision anomalies. *J Optom*. 2014;7(4):178-192. doi:10.1016/j.optom.2014.06.005
6. Cacho-Martínez P, Cantó-Cerdán M, Carbonell-Bonete S, García-Muñoz Á. Characterization of Visual Symptomatology Associated with Refractive, Accommodative, and Binocular Anomalies. *J Ophthalmol*. 2015;2015:895803. doi:10.1155/2015/895803
7. Sánchez-González MC, Pérez-Cabezas V, López-Izquierdo I, et al. Is it possible to relate accommodative visual dysfunctions to neck pain? *Ann N Y Acad Sci*. 2018;1421(1):62-72. doi:10.1111/nyas.13614
8. García-Muñoz Á, Carbonell-Bonete S, Cantó-Cerdán M, Cacho-Martínez P. Accommodative and binocular dysfunctions: prevalence in a randomised sample of university students. *Clin Exp Optom*. 2016;99(4):313-321. doi:10.1111/cxo.12376
9. Montés-Micó R. Prevalence of general dysfunctions in binocular vision. *Ann Ophthalmol*. 2001;33(3):205-208. doi:10.1007/s12009-001-0027-8
10. Cacho-Martínez P, García-Muñoz Á, Ruiz-Cantero MT. Is there any evidence for the

validity of diagnostic criteria used for accommodative and nonstrabismic binocular dysfunctions? *J Optom*. 2014;7(1):2-21. doi:10.1016/j.optom.2013.01.004

11. Cacho-Martínez P, García-Muñoz Á, Ruiz-Cantero MT. Do we really know the prevalence of accomodative and nonstrabismic binocular dysfunctions? *J Optom*. 2010;3(4):185-197. doi:10.1016/S1888-4296(10)70028-5

12. Morgan M. The clinical aspects of accommodation and convergence. *Am J Optom Arch Am Acad Optom*. 1944;21:301-3013.

13. Scheiman M, Wick B. Diagnosis and General Treatment Approac. In: Scheiman M, Wick B, eds. Clinical management of binocular vision: heterophoric, accommodative, and eye movement disorders. In: 4th ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2014:8.

14. Rozanova OI, Shchuko AG, Mischenko TS. Fundamentals of Presbyopia: visual processing and binocularity in its transformation. *Eye Vis*. 2018;5(1):1. doi:10.1186/s40662-018-0095-0

15. Leat SJ, Krishnamoorthy A, Carbonara A, Gold D, Rojas-Fernandez C. Improving the legibility of prescription medication labels for older adults and adults with visual impairment. *Can Pharm J / Rev des Pharm du Canada*. 2016;149(3):174-184. doi:10.1177/1715163516641432

16. Leat SJ, Zecevic AA, Keeling A, Hileeto D, Labreche T, Brymer C. Prevalence of vision loss among hospital in-patients; a risk factor for falls? *Ophthalmic Physiol Opt*. 2018;38(1):106-114. doi:10.1111/opo.12428

17. Lord SR, Clark RD, Webster IW. Visual acuity and contrast sensitivity in relation to falls in an elderly population. *Age Ageing*. 1991;20(3):175-181.

18. Vale A, Buckley JG, Elliott DB. Gait Alterations Negotiating A Raised Surface Induced by Monocular Blur. *Optom Vis Sci*. 2008;85(12):1128-1134. doi:10.1097/OPX.0b013e31818e8d2a

19. Wubben TJ, Guerrero CM, Salum M, Wolfe GS, Giovannelli GP, Ramsey DJ. Presbyopia:

a pilot investigation of the barriers and benefits of near visual acuity correction among a rural Filipino population. *BMC Ophthalmol*. 2014;14(1):9. doi:10.1186/1471-2415-14-9

20. Baumeister M, Kohnen T. Akkommodation und Presbyopie. *Der Ophthalmol*. 2008;105(6):597-610. doi:10.1007/s00347-008-1761-8

21. Palomo-Alvarez C, Puell MC. Binocular function in school children with reading difficulties. *Graefes Arch Clin Exp Ophthalmol*. 2010;248(6):885-892. doi:10.1007/s00417-009-1251-y

22. Morgan MW. Analysis Of Clinical Data. *Am J Optom Arch Am Acad Optom*. 1944;21(12):477-491.

23. Fincham EF, Walton J. The reciprocal actions of accommodation and convergence. *J Physiol*. 1957;137(3):488-508. doi:10.1113/jphysiol.1957.sp005829

24. Maxwell J, Tong J, Schor CM. The first and second order dynamics of accommodative convergence and disparity convergence. *Vision Res*. 2010;50(17):1728-1739. doi:10.1016/j.visres.2010.05.029

25. Sheedy JE, Saladin JJ. Exophoria at near in presbyopia. *Am J Optom Physiol Opt*. 1975;52(7):474-481.

26. Cantó-Cerdán M, Cacho-Martínez P, García-Muñoz Á. Measuring the heterophoria: Agreement between two methods in non-presbyopic and presbyopic patients. *J Optom*. 2018;11(3):153-159. doi:10.1016/j.optom.2017.10.002

27. Wick B. Vision training for presbyopic nonstrabismic patients. *Am J Optom Physiol Opt*. 1977;54(4):244-247.

28. Aziz S, Cleary M, Stewart HK, Weir CR. Are Orthoptic Exercises an Effective Treatment for Convergence and Fusion Deficiencies? *Strabismus*. 2006;14(4):183-189. doi:10.1080/09273970601026185

29. Jiménez R, Pérez MA, García JA, González MD. Statistical normal values of visual parameters that characterize binocular function in children. *Ophthalmic Physiol Opt*.

2004;24(6):528-542. doi:10.1111/j.1475-1313.2004.00234.x

30. Scheiman M, Wick B. Diagnosis and General Treatment Approac. In: Scheiman M, Wick B, eds. Clinical management of binocular vision: heterophoric, accommodative, and eye movement disorders. In: 4th ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2014:12.

31. Hrynchak PK, Herriot C, Irving EL. Comparison of alternate cover test reliability at near in non-strabismus between experienced and novice examiners. *Ophthalmic Physiol Opt*. 2010;30(3):304-309. doi:10.1111/j.1475-1313.2010.00723.x

32. Johns HA, Manny RE, Fern K, Hu Y-S. The intraexaminer and interexaminer repeatability of the alternate cover test using different prism neutralization endpoints. *Optom Vis Sci*. 2004;81(12):939-946.

33. Scheiman M, Wick B. Diagnosis and General Treatment Approach. In: Scheiman M, Wick B, eds. *Clinical Management of Binocular Vision: Heterophoric, Accommodative, and Eye Movement Disorders*. 4th ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2014.

34. Rosenfield M, Ciuffreda KJ, Ong E, Super S. Vergence adaptation and the order of clinical vergence range testing. *Optom Vis Sci*. 1995;72(4):219-223.

35. Gall R, Wick B, Bedell H. Vergence facility: establishing clinical utility. *Optom Vis Sci*. 1998;75(10):731-742.

36. Jiang BC, Gish KW, Leibowitz HW. Effect of luminance on the relation between accommodation and convergence. *Optom Vis Sci*. 1991. doi:10.1097/00006324-199103000-00010

37. Baker FJ, Gilmartin B. The effect of incipient presbyopia on the correspondence between accommodation and vergence. *Graefe's Arch Clin Exp Ophthalmol*. 2002;240(6):488-494. doi:10.1007/s00417-002-0483-x

38. Palomo Alvarez C, Puell MC, Sánchez-Ramos C, Villena C. Normal values of distance heterophoria and fusional vergence ranges and effects of age. *Graefes Arch Clin Exp Ophthalmol*. 2006;244(7):821-824. doi:10.1007/s00417-005-0166-5

39. Pellizzer S, Siderov J. Assessment of vergence facility in a sample of older adults with presbyopia. *Optom Vis Sci*. 1998;75(11):817-821.

40. Scheiman M, Wick B. Diagnosis and General Treatment Approach. In: Scheiman M, Wick B, eds. *Clinical Management of Binocular Vision: Heterophoric, Accommodative, and Eye Movement Disorders*. 4th ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2014:8.

41. Bruce AS, Atchison DA, Bhoola H. Accommodation-convergence relationships and age. *Invest Ophthalmol Vis Sci*. 1995;36(2):406-413.

42. Heron G, Charman WN, Schor CM. Age changes in the interactions between the accommodation and vergence systems. *Optom Vis Sci*. 2001;78(10):754-762.

Figure Captions

Figure 1. Study flow chart

Figure 2. Lineal regression graphs of; (A) Distance recovery negative fusional vergence (NFV) versus age. (B) Distance recovery positive fusional vergence (PFV) versus age. (C) Near blur PFV versus age. (D) Near break PFV versus age. (E) Near recovery PFV versus age. (F) VF versus age.

Figure 3. Boxplot graphs for nonpresbyopic and presbyopic groups; (A) Near heterophoria with compensation. (B) Distance recovery PFV. (C) Near blur PFV. (D) Near break PFV. (E) Near recovery PFV. (F) Vergence facility.

Table 1. Correlation between horizontal fusional vergences and vergence facility variables versus age

Variable	r	*P* Value	R^2	Regression Line
Recovery distance NFV, Δ with age	-0.25	<0.01	0.038	y= 5.86 - 0.03 x
Recovery distance PFV, Δ with age	-0.30	<0.01	0.094	y= 12.85 - 0.1 x
Blur near PFV, Δ with age	-0.32	<0.01	0.088	y= 18.17 - 0.14 x
Break near PFV, Δ with age	-0.27	<0.01	0.075	y= 25.84 - 0.15 x
Recovery near PFV, Δ with age	-0.32	<0.01	0.111	y= 18.34 - 0.17 x
Vergence facility, Δ with age	-0.36	<0.01	0.150	y= 13.85 - 0.12 x

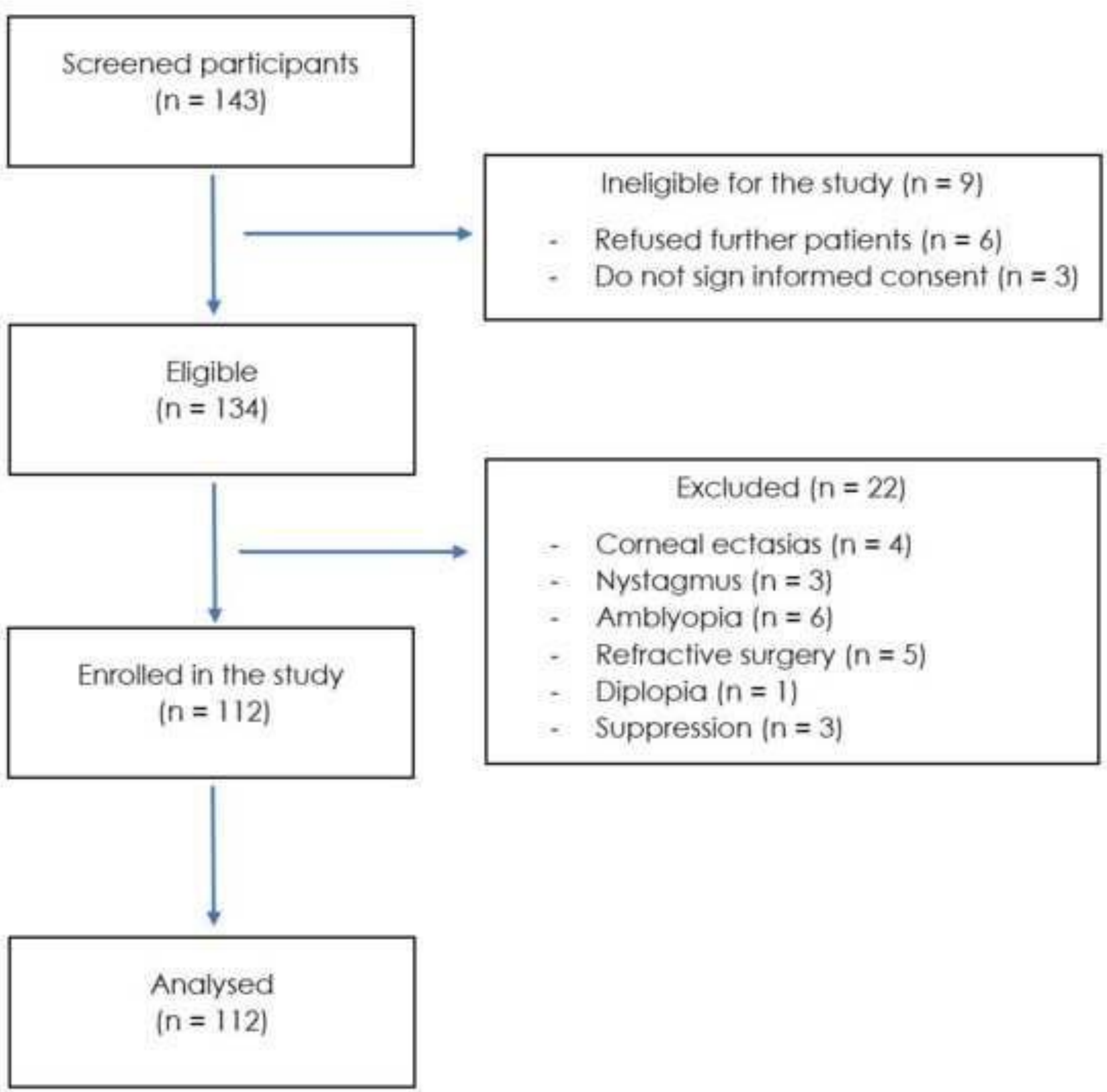
NFV, negative fusional vergence; PFV, positive fusional vergence; Δ, prismatic diopters.

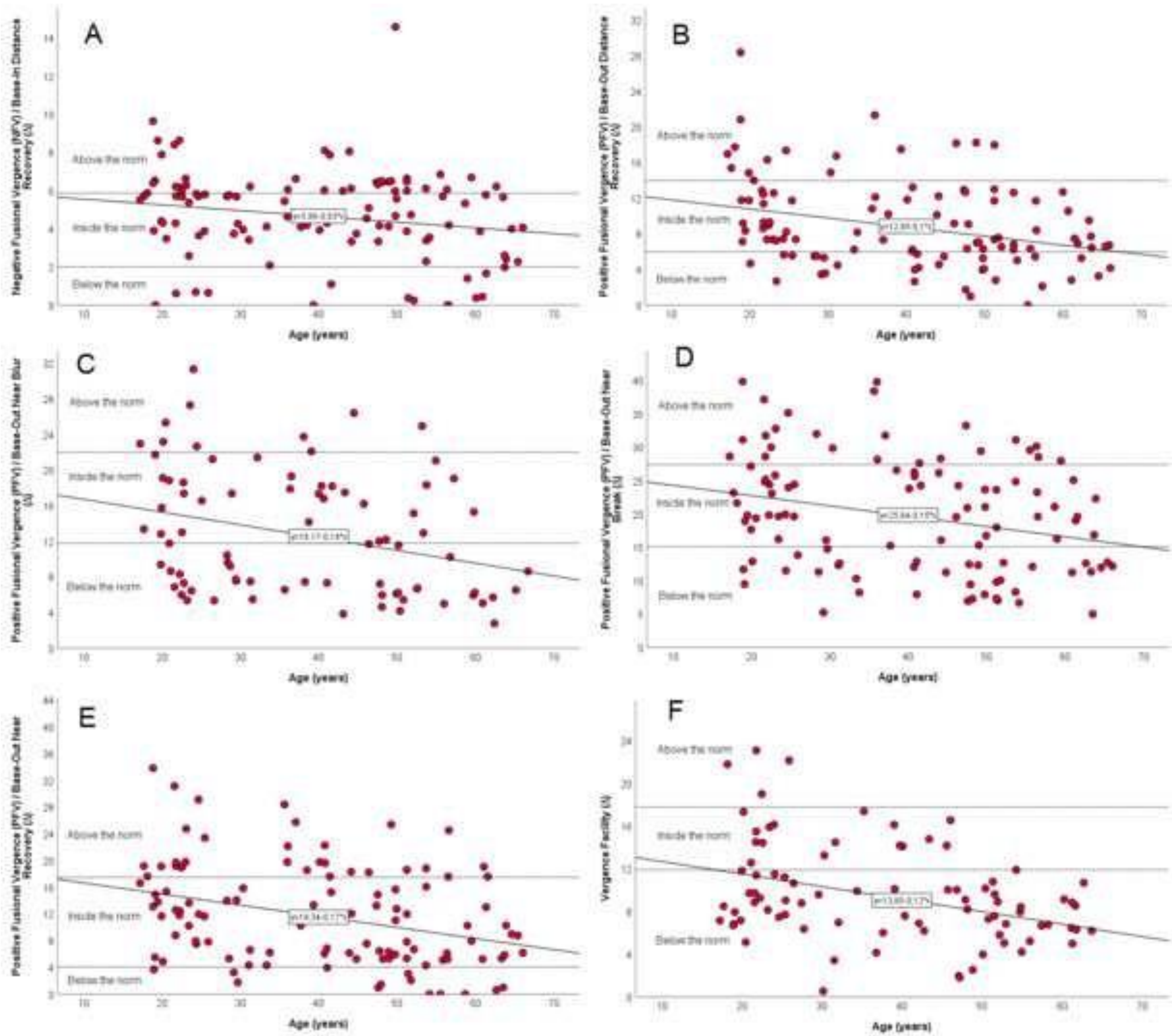
Table 2. Descriptive analysis of horizontal heterophoria, horizontal fusional vergences and vergence facility

			Group age range (years)								*P* value
			From 18 to 39 years				From 40 to 65 years				
			n	Mean	SD	Rango	n	Mean	SD	Rango	
Age (years)			49	25.29	6.04	21	62	52.18	7.59	25	<0.01*
Distance HH	without Compensation (Δ) ¶		49	0.39X	4.96	30	61	0.52X	1.97	15	0.86
	with Compensation (Δ) ¶		33	0.70X	3.45	20	34	0.45X	1.14	6	0.70
Near HH	without Compensation (Δ) ¶		48	5.73X	9.33	50	59	6.29X	5.90	24	0.71
	with Compensation (Δ) ¶		33	3.15X	8.90	36	48	6.87X	6.76	29	< 0.05*
BI or NFV	Distance	Break (Δ)	49	10.20	3.16	12	61	9.80	3.71	15	0.55
		Recovery (Δ)	49	4.92	2.09	9	61	4.43	2.52	14	0.27
	Near	Blur (Δ)	39	12.23	5.38	25	47	10.45	4.61	17	0.10
		Break (Δ)	49	18.04	4.55	26	62	17.94	5.44	26	0.91
		Recovery (Δ)	49	12.41	4.59	20	62	11.66	5.13	22	0.42
BO or PFV	Distance	Blur (Δ)	42	12.45	5.56	22	33	12.36	6.33	20	0.94
		Break (Δ)	49	20.02	6.89	28	57	17.86	7.12	30	0.11
		Recovery (Δ)	49	10.35	5.29	24	58	7.48	4.35	18	<0.01*
	Near	Blur (Δ)	42	14.21	7.30	26	39	11.08	6.40	24	<0.05*
		Break (Δ)	49	22.12	8.70	34	60	17.67	7.77	26	<0.01*
		Recovery (Δ)	49	14.24	7.80	31	60	9.55	6.71	24	<0.01*
Vergence Facility (Δ)			44	10.70	4.96	21	43	8.07	3.41	14	<0.01*

HH: Horizontal Heterophoria; NFV: Negative Fusional Vergence; PFV: Positive Fusional Vergence; BI: Base-in; BO: Base-out. SD, Standard Deviation. * statistically significant. ¶ X: Exophoria, E:Esophoria.

Figure


Screened participants
(n = 143)
Ineligible for the study (n = 9)
- Refused further patients (n = 6)
- Do not sign informed consent (n = 3)
Eligible
(n = 134)
Excluded (n = 22)
- Corneal ectasias (n = 4)
- Nystagmus (n = 3)
- Amblyopia (n = 6)
- Refractive surgery (n = 5)
- Diplopia (n = 1)
- Suppression (n = 3)
Enrolled in the study
(n = 112)
Analysed
(n = 112)


A
B
C
D
E
F
Above the norm
Inside the norm
Below the norm
Age (years)

Figure

Click here to access/download;Figure;Figure 3.tiff