




A review of normative data for parameters of functional non-strabismic binocular vision



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Background: There was a need to document population-expected normative data for parameters of non-strabismic binocular vision (NSBV) as the analysis and diagnosis of binocular vision disorders required comparison of patient's clinical signs with expected data in their specific population.

Aim: This article sought to review and map population-expected continental normative data for visual function parameters for evaluating the functional non-strabismic accommodative and vergence system, as these systems are very relevant to evaluate the comfort of visual system.

Method: Search engines – namely, Google Scholar, Microsoft Academic, Web of Science database and Ovid MEDLINE database – were used to search studies published in English across different continents using keywords such as 'normative or expected data' and 'specific NSBV parameter'. Results were summarised in tables for easy comparison; data were presented based on the geographical location, year of publication, demographics of the population studied and the techniques used for measuring the parameters. A summary of observed challenges with reviewed works and recommendations for the future studies are indicated. The article is delimited to studies published between 1910 and September 2019 only.

Results: Most of the studies investigated specific parameters of either accommodation only or vergence only; few recent studies have comprehensively investigated both parameters. Most studies were conducted in North America followed by Asia and Europe, with a few in Africa. No studies were found with Oceania populations. There were discrepancies and differences in methodologies and techniques used by the studies reviewed and normative data varied among different continents and different populations within each continent.

Conclusion: As the observed differences in reviewed studies could be attributed to differences in test techniques, the future studies should consider using identical, reliable, repeatable, objective and subjective techniques with good methodological designs to clarify these results. More studies should be conducted in African and Oceania populations.

Keywords: non-strabismic binocular vision (NSBV); visual function parameters; accommodative parameters; vergence parameters.

Introduction

According to O'Connor,¹ normative data comprise observations that characterise what is usual or expected in a defined or reference population. This definition emphasises 'reference population' indicating that normative data vary among populations. In relation to binocular vision (BV), normative data here refer to population-expected visual function parameters for vergence and accommodation. These parameters of accommodation and vergence are important measures to consider in assessing and classifying non-strabismic BV status and anomalies.^{2,3} Recent studies^{4,5,6,7,8,9} have acknowledged that visual function parameters differ among different populations and indicate the need for population-specific normative data. Population, in this sense, is defined in terms of race, ethnicity, gender and age as these are the variables thought to influence accommodation and vergence.^{4,10,11} These differences in parameters can be attributed to the anatomic differences in the eye,^{12,13} which can lead to differences in refractive status^{14,15} and in parameters of accommodation and vergence.^{2,3} Accurate BV examination, diagnosis and management require reference to the

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normative data in the specific patient's population.^{6,7,8,9} Even though the aetiology of BV anomalies is either functional or non-functional in origin,² this article reviews existing literature on normative data for vision parameters of functional, non-strabismic accommodative and vergence systems.

Methods

A review of literature was conducted using search engines, namely, Google Scholar, Microsoft Academic, Web of Science database and Ovid MEDLINE database. Keywords such as 'normative or expected non-strabismic BV functions', 'normative or expected vergence functions', 'normative or expected accommodative functions', 'normal stereopsis' and 'normative or expected with specific visual function parameter' (e.g. normative or expected near point of convergence [NPC]) revealed numerous papers. For original studies, all articles in their references were also included in the search. This article presents studies written in English only and is aimed at establishing evidence-based normative data for BV parameters. Emphasis was placed on the following: general studies in terms of race, specific studies of children, adults, and clinic and non-clinic patients. Studies are presented according to geographical region and year of publication arranged chronologically. Emphasis is also placed on the specific test techniques used in studies. The use of the term 'distance' means the technique was performed at 6 m, and the use of the term 'near' means the technique was performed at 0.4 m. A summary of observed challenges with reviewed papers and recommendations for future studies are also presented. This article is limited to studies published between 1910 and September 2019.

Ethical considerations

Ethical clearance was obtained from the Biomedical Research Ethics Committee (BREC) at the University of KwaZulu-Natal (number: BE275/17).

Results

Normative data studies in North and South America

Early studies on normative data for BV parameters (Table 1) commenced in the 1940s and were conducted mainly in the United States. Some early studies¹⁶ had investigated problems in schoolchildren and found most of these to be near vision function anomalies. Other studies investigated the most probable or expected data to compare findings. Commonly, Donder's and Duane's tables and Hofstetter's equations served as standard expected measures for evaluating amplitude of accommodation (AA).¹⁷ Haines¹⁸ and Morgan¹⁹ determined normal values for visual function parameters of accommodation and vergence in pre-presbyopic patients. Shepard²⁰ determined expected vergence function data in 56 adults and children. Morgan¹⁹ indicated that his expected values applied to populations and not to individuals and emphasised that they do not necessarily indicate that a patient has an anomaly of BV if only one parameter falls outside the normal range.²¹ Wesson²² focused on studying fusional vergences with the use of prism bars in 79 clinic participants aged 4–70 years.

The Optometric Extension Programme (OEP) expected values were not derived from population statistics but resulted from thousands of clinic participants of varying age groups.²³ These values went through a standardisation process from the clinical experiences of practitioners;²³ the specific process of standardisation, however, was not defined

TABLE 1: Expected values for vergence and accommodative functions from the early American studies between 1910 and 1999.

BV Test	Haines ¹⁸	Shepard ²⁰	Morgan ^{19,21}	OEP ²³	Wesson ²²	Scheiman et al. ²⁹	Sheedy and Saladin ³⁴
Study population	Non-presbyopes	Adults and children	Pre-presbyopes	Clinic patients	4–70-years-old	Schoolchildren	Optometry students
D LH (pd)	0 ± 1 VG	1 exo ± 2.5	1 exo ± 2	0.5 exo	-	-	1 exo ± 4
N LH (pd)	4.8 exo ± 3.2 VG	5 exo ± 5	3 exo ± 3	6.0 exo	-	-	-
D VH (pd)	<1 pd VG	-	-	-	-	-	-
D BI (break)	-	-	7 ± 3	9	-	-	8 ± 3
D BI (recovery)	-	-	4 ± 2	5	-	-	5 ± 3
D BO (blur)	-	-	9 ± 4	7	-	-	15 ± 7
D BO (break)	-	-	19 ± 8	19	-	-	28 ± 10
D BO (recovery)	-	-	10 ± 4	10	-	-	20 ± 11
N BI (blur)	-	-	13 ± 4	14	-	-	-
N BI (break)	19–25	20 ± 5.5 A	21 ± 4	22	13 ± 5 PB	12 ± 5 PB	-
N BI (recovery)	8–18	11 ± 4 A	13 ± 5	18	10 ± 4 PB	7 ± 4 PB	-
N BO (blur)	-	-	17 ± 5	15	-	-	-
N BO (break)	17–28	25 ± 11 A	21 ± 6	21	19 ± 11 PB	23 ± 8 PB	-
N BO (recovery)	12–22	13 ± 7.5A	11 ± 7	15	14 ± 9 PB	16 ± 6 PB	-
AA (D)	DOT	Minimum 9 D (8 years)	18 – (1/3) age ± 2.00 PU DUT	-	-	-	-
AR (D)	1.0 ± 0.4	-	0.50 ± 0.50 FCC	0.50 FCC	-	-	-
NRA	+2.06 ± 0.2	-	+2.00 ± 0.50	+2.00	-	-	-
PRA	-2.00 ± 0.4	-	-2.37 ± 1.00	-2.25	-	-	-

D, distance which means the test was done at 6 m; N, near which means the test was done at 0.4 m; LH, lateral heterophoria; VG, Von-Graefe technique; pd, Prism Dioptre; VH, vertical heterophoria, BI, base in; BO, base out; PB, prism bar; exo, exophoria; AA, amplitude of accommodation; AR, accommodation response; AF, accommodative facility; PU, push up technique; NRA, negative relative accommodation; PRA, positive relative accommodation; DOT, Donder's Table; DUT, Duane's table; FCC, fused cross-cylinder method; A, general working adults; hyphen, means not applicable as the specific study did not report values for such parameters.

clearly. The OEP data were minimum estimated values required for persons to withstand the impact of near point stress whilst maintaining satisfactory performance; thus, standard deviations were not indicated.²³

These classic studies^{18,19,20} on expected values did not investigate data for all the parameters of vergence and accommodation. None of the studies involved normative data for NPC break and recovery, vertical heterophorias, accommodative facility or stereopsis (Table 1). Freier and Pickwell²⁴ in their study on physiological exophoria sampled 663 participants aged 5–74 years and, using the Maddox rod technique, recorded values for distance heterophoria (0.84–1.50 Δ esophoria) and near heterophoria (0.34–3.83 Δ exophoria). They reported that, for distance vision, the mean heterophoria in optometric clinic patients remains unchanged throughout life.²⁴ Another study, however, followed up 100 healthy young individuals for 20 years and found an increase in distance esophoria.²⁵

Rouse and Hutter²⁶ investigated normative data for accommodative response in elementary schoolchildren and recorded an expected value of 0.3 D \pm 0.3 D. Zeller²⁷ investigated normative data for accommodative facility in 18–30-year-old participants and reported 7.7 cycles per minute (cpm) \pm 5.2 cpm expected. Scheiman et al., however, studied normative data for accommodative facility in elementary schoolchildren and found 5.0 cpm \pm 2.5 cpm expected.²⁸ Scheiman et al. also investigated normative data for step vergence in elementary schoolchildren in the United States and provided expected measures for negative fusional vergence and positive fusional vergence breaks and recovery (Table 1).²⁹

Hayes et al. investigated the normative values of NPC in third and sixth grade elementary schoolchildren using the push-up (PU) technique and found a break of 4.3 cm \pm 3.4 cm and a recovery of 7.2 cm \pm 3.9 cm.³⁰ A study by Walline et al. investigated heterophoria in 1495 schoolchildren using the cover test and found heterophoria measures for different levels.³¹ Walline et al.³¹ determined distance heterophoria in kindergarten children (0.01 Δ exophoria \pm 0.39 Δ exophoria), second-grade children (0.04 Δ exophoria \pm 0.67 Δ exophoria) and fifth-grade children (0.02 Δ exophoria \pm 0.51 Δ exophoria). The authors³¹ determined near heterophoria in kindergarten children (0.62 Δ exophoria \pm 1.46 Δ exophoria), second-grade children (0.49 Δ exophoria \pm 0.60 Δ exophoria) and fifth-grade children (0.26 Δ exophoria \pm 1.59 Δ exophoria). Jackson and Goss³² using the Von Graeffe technique on 244 participants aged 9–15 years recorded distance heterophoria of 1 Δ exophoria \pm 2 Δ exophoria and near heterophoria of 3 Δ exophoria \pm 4 Δ exophoria. Letourneau and Giroux,³³ in a sample of 2035 North American participants aged 6–13 years, found a distance heterophoria of 0.57 Δ esophoria \pm 2.54 Δ exophoria, and a near heterophoria of 0.78 Δ exophoria \pm 4.51 Δ exophoria in 2029 participants using the Maddox rod technique. Sheedy and Saladin³⁴ reported normative data for heterophorias and distance fusional vergence amplitudes at far among healthy optometry

students with no asthenopic symptoms (Table 1). However, the authors did not indicate whether values were applicable to all age groups or to specific ages only.

The challenge with studies conducted in the United States is that the racial profile of a specific population studied, whether white, black or Latino Americans, was not specified. Most of the early studies conducted in the United States did not specify the age range of participants but only described the study population as presbyopic, pre-presbyopic, schoolchildren, adults and clinic patients (Table 1).

More recent studies (Table 2) conducted in the United States, such as Scheiman et al.,³⁵ have determined normative data for NPC using different targets, namely, accommodative target, penlight and penlight with red-green glasses. Normal participants with monocular 20/20 visual acuity for distance and near with the best refractive correction had no strabismus or non-strabismic binocular vision (NSBV) anomalies using traditional normative values as standards.^{19,27} Lyon et al.³⁶ investigated normative data for fusional vergence break and recovery parameters at near for base-out and base-in prisms as well as the modified Thorington test phoria in 6–11-year-old normal children (Table 2). Maples et al.³⁷ investigated for NPC norms in elementary schoolchildren aged 8–13 years using the push-up technique and found a break of 4.2 cm \pm 3.4 cm and a recovery of 9.8 cm \pm 4 cm (Table 2). The expected values for accommodative and vergence testing reported by Scheiman and Wick³ were obtained from the results of different studies, including Morgan's¹⁹ table of expected findings. These values by Scheiman and Wick³ comprehensively reported normative data (Tables 2 and 3) for all parameters of accommodation and vergence required for diagnosis and management of functional NSBV anomalies and served as modern standards.

Taub and Shallow-Hoffman³⁸ compared three clinical tests of accommodation with Hofstetter's norms in 6–13-year-old children using the push-up technique to determine a mean AA of 15.4 D (Table 3). Based on the fact that Hofstetter's equations for AA were derived from studies that have various limitations, Castagno et al.³⁹ conducted a study in 6–16-year-old urban children in Brazil to investigate expected data for the amplitude of accommodation. Their study³⁹ reported median AA data for specific ages (Table 3) and proposed the use of median and percentiles to define AA standards to avoid outlier effects. In Castagno et al.'s study,³⁹ in which 2.8% of participants' AA was 2 D lower than Hofstetter's minimum, normal participants were children with visual acuity better than 20/25 in either eye after fogging test, stereoscopic vision better than 100 sec arc, and not having strabismus.

With limited data from different countries, in America, the expected data for accommodative and vergence parameters compiled by Scheiman and Wick³ serve as current standards for American populations as it indicates data for different age

TABLE 2: Normative data for vergence parameters in America from 2000 to 2019.

Authors	Study population	NPC (break) cm	NPC (recovery) cm	DLH (pd)	NLH (pd)	Distance: BI (break)	Distance BI (recovery)	Distance BO (blur)	Distance BO (break)	Distance BO (recovery)	Near: BI (blur)	Near BI (break)	Near BI (recovery)	Near BO (blur)	Near BO (break)	Near BO (recovery)	Vergence facility
Scheiman et al. ³⁵	US adults	AT 2.5 ± 1.7; PLRG 2.4 ± 2.1; Penlight 2.1 ± 1.9	AT 4.4 ± 2.7; PLRG 4.4 ± 3.3; Penlight 3.7 ± 2.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lyon et al. ³⁶	6–11-year-old US children	-	-	MTT 2 eso	MTT 1.0 exo ± 4	-	-	-	-	-	-	16 ± 7	10 ± 5	21 ± 11	13 ± 8	-	-
Maples et al. ³⁷	8–13-year-old US children	Push-up 4.2 ± 3.4	Push-up 9.8 ± 4	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Scheiman and Wick ³	US population	AT 5 ± 2.5; PLRG 7 ± 4.0	AT 7 ± 3; PLRG 10 ± 5.0	CT 1 exo ± 2	CT 3 exo ± 3	Ph 7 ± 3; PB 7 ± 3 adults	Ph 4 ± 2; PB 4 ± 2 adults	Ph 9 ± 4; PB -	Ph 10 ± 8; PB 11 ± 7 adults	Ph 10 ± 4; PB 7 ± 2 adults	Ph 13 ± 4; PB -	Ph 21 ± 4; PB 13 ± 6 adults; 12 ± 5 (7–12 years)	Ph 13 ± 5; PB 10 ± 5 adults; 7 ± 4 (7–12 years)	Ph 17 ± 5; PB -	Ph 21 ± 6; PB 19 ± 9 adults; 23 ± 8 (7–12 years)	Ph 11 ± 7; PB 14 ± 7 adults; 16 ± 6 (7–12 years)	12 base-out; 15 cpm ± 3 cpm

NPC, Near point of convergence; AT, accommodative target; PLRG, penlight with red green lens; DLH, distance lateral heterophoria; NLH, near lateral heterophoria; MTT, Modified Thorington test; CT, cover test; pd, prism dioptre; Ph, phoropter; PB, prism bar; BO, base out; BI, base in; cpm, cycles per minute; -, (hyphen), means not applicable as the specific study did not report values for such parameters.

‡, Distance here means the test was done at 6 m.

‡, Near here means the test was done at 0.4 m.

TABLE 3: Normative data for accommodative parameters in America from 2000 to 2019.

Authors	Study population	Stereo acuity	Amplitude of accommodation	Accommodative response (D)	Monocular accommodative facility (MAF) (cpm)	Binocular accommodative facility (BAF) (cpm)	NRA	PRA	AC/A ratio
Scheiman and Wick report ³	US population, age specified for parameter	CS (20 sec arc); GRDS (Appreciable stereopsis)	Push-up 1.8 – (1/3) age ± 2 D Minus lens test 2 D < push-up	MEM 0.50 ± 0.25 FCC 0.50 ± 0.50	± 2 D Flippers with ART 6-year: 5.5 ± 2.5 7-year: 6.5 ± 2.0 8-year: 7.0 ± 2.5 Adults 13–30 years: 11 ± 5	± 2 D Flippers with ART 6-year: 3 ± 2.5 7-year: 3.5 ± 2.5 8–12 years: 5 ± 2.5 Adults: 10 ± 5	2.00 ± 0.50	-2.37 ± 1.00	NS 4:1 ± 2
Taub and Shallow-Hoffman ³⁸	6–13-year-old US children	-	Push-up 15.4 D.	-	-	-	-	-	-
Castagno et al. ³⁹	6–16-year-old Brazilian children	-	Push-up 14.3 D (6–16 years) 15.5 D (6–10 years) 14.2 D (11–13 years) 13.3 D (14–15 years) 12.9 D (16 years)	-	-	-	-	-	-

MEM, monocular estimation method; CS, Contour stimuli; GRDS, gross random dot stimuli; FCC, Fused Cross Cylinder; ART, accommodative rock target; AC/A, accommodative convergence over accommodation; NRA, negative relative accommodation; PRA, positive relative accommodation; NS, not specified technique; -, (hyphen), means not applicable as the specific study did not report values for such parameters.

groups within the continent. Castagno et al.'s³⁹ values for AA serve as current standards for Brazilian children.

Normative data studies in Europe

The oldest study reviewed⁴⁰ among Europeans was published in 1990. Dowley⁴⁰ sampled 925 participants aged 18–42 years and recorded a distance heterophoria of orthophoria using modified Maddox techniques. The participants had stable refractive errors, were asymptomatic and had stereopsis of 60 sec arc using the TNO stereo test. All other studies reviewed were conducted in the 21st century and few have investigated both vergence and accommodation parameters.

Jimenez et al.⁵ conducted a study in a non-clinical paediatric population in Spain to evaluate the evolution of accommodative functions and development of ocular movements. In this study,⁵ they provided mean expected values for each age group for the parameters of accommodation, namely, accommodative amplitude, accommodative facility and accommodative response. The mean values with standard deviations of accommodative parameters measured for participants (aged 6–12 years) are provided in Table 4. Another report by Jimenez et al.¹⁰ in elementary schools in the city of Granada, Spain, investigated binocular function in a paediatric population. Participants in that study¹⁰ had no ocular diseases, suppression or systemic diseases. According to the authors,¹⁰ differences in age groups, although statistically significant, were not clinically relevant.

Sterner et al.⁴¹ investigated AA in schoolchildren in Sweden. Normal participants for the study comprised children with no astigmatism, amblyopia, strabismus or anisometropia. According to the study,⁴¹ the AA measures (Table 4) were not as good as expected when compared with Hofstetter's minimum values. McClelland⁴² reported normative data for accommodative lag using dynamic retinoscopy (Nott retinoscopy) in healthy school-age children in Northern Ireland. In that study,⁴² only schoolchildren with visual acuity of 6/6 or better and children with no uncorrected refractive errors were selected as normal participants. McClelland⁴² recorded age-expected normative data across age groups for each of three stimuli test distances with accommodative demands of 4 D, 6 D and 10 D as indicated in Table 4. There was no statistically significant difference in mean accommodative responses across the age groups for the three stimuli test distances.⁴²

Álvarez et al.⁴³ studied whether reference values for distance heterophoria and fusional vergence ranges for classic studies were applied to all age groups. Álvarez et al.⁴³ determined ranges for these parameters in age categories in a visually normal large non-clinic general Spanish population. However, Alvarez et al.'s data only for the age group of 21–30 years and 31–40 years are provided here (Table 4) and there seem to be some differences among these age groups.⁴³ Glerow et al.⁴⁴ in their study of Swedish schoolchildren with normal stereopsis have reported expected measures for the

AA, accommodative facility and vergence facility (Table 4). Glerow et al.⁴⁴ found values for binocular AA to be similar to Hofstetter's average, whilst monocular AA values were significantly lower. Lanca and Rowe,⁴⁵ in a cross-sectional study, reported certain BV measures in asymptomatic Portuguese children (Table 4). These children had best-corrected visual acuity of 0.0 Log MAR in either eye, compensated heterophoria of 10 prism dioptres, full ocular rotations, presence of fusional vergence and stereopsis of 60 sec arc or better.

There is an observed larger difference in expected stereo acuity measures between the children in Spain⁵ and that in Portugal.⁴⁵ Stereo acuity of 60 sec arc or better could serve as a current guide for children in Europe. With limited information on NPC in Europe, the current standards for push-up NPC break for European children aged less than 14 years are within an estimated average of 6.4 cm as obtained from two European studies.^{10,45} The expected distance and near-lateral heterophoria (NLH) for European children may range from 5 Δ esophoria to 1 Δ exophoria, and orthophoria to 4 Δ exophoria, respectively.^{10,43,45} These three studies, however, used different techniques, making value applicability difficult. The expected average push-up monocular AA for European children aged 6–13 years is estimated to be at 10 D – 16 D.^{5,41,44} The accommodative response (lag) for European children aged 4–15 years may be estimated at 0.00 D – 0.80 D.^{5,42} The monocular accommodative facility (MAF) and binocular accommodative facility (BAF) measures for European children are estimated at not more than 11 cpm^{5,44} and 9 cpm, respectively. The authors did not find any study in Europe that has investigated normative data for positive relative accommodation (PRA) and negative relative accommodation (NRA). Jimenez et al.^{5,10} did not evaluate for NRA and PRA, indicating that these parameters evaluate interactions between accommodative and vergence systems.

Normative binocular vision data studies in Asia

The first study in Asia by Kim⁴⁶ in 1979 determined normal values for AA among South Koreans and divided participants into 13 groups based on age. This study used the minus-lens-to-blur technique using Duane's single fine thread as the target. Values for age groups less than 30 years are indicated in Table 6. All other studies reviewed were published in the 21st century and four out of six studies reported measures for both parameters of accommodation and vergence; however, these four studies did not report on all parameters of accommodation and vergence.

Chen et al.⁴⁷ in their study on near visual functions in children sampled 268 participants aged 2–15 years using the Modified Maddox technique that found distance phoria of 1.29 Δ exophoria. Chen and Abidin⁴ conducted a study comprising normal primary schoolchildren in Malaysia with a visual acuity of 6/6 and better with no history of previous eye problems. Parameters measured included accommodative facility, accommodation accuracy, relative accommodation,

TABLE 4: Normative data for non-strabismic binocular vision parameters in Europe.

Authors	Settings	Participants	Sample size	Non-strabismic binocular vision parameters															
				Stereo acuity (sec arc)	NPC (break) cm	NPC (recovery) cm	LH (distance) [†] pd	VH (distance) [†] pd	LH (near) [‡] pd	VH (near) [‡] pd	BI (break)	BI (recovery)	BO (break)	BO (recovery)	Vergence facility (cpm)	AC/A ratio	AA (D)	AA (D)	MAF (cpm)
Jimenez et al. ³	Spain, Granada	6–12 years Spanish children	1056	Random stereo test 2.2 ± 6	MTT 0.14	PU with RL 6.75 ± 6.3 PU with PL 4.6 ± 3.6	MTT 0.7 eso ± 4.4 exo ± 0.14	MTT 0.1 exo ± 3.8	PB 11 ± 3 near	PB 7 ± 3	-	-	-	-	-	B 12.82 ± 3.60 M 12.56 ± 3.08	MEM 7.16 ± 3.24 0.39 ± 0.44	7.16 ± 3.24	3.84 ± 2.91 NS
Jimenez et al. ¹⁰	Spain, Granada	6–12 years Spanish children	1056	-	-	-	-	-	-	-	-	PB 13 ± 6 near	Grad 1.9 ± 0.54 Calc 4.6 ± 3.4	-	-	-	-	-	
Sternier et al. ⁴¹	Sweden	6–12 years Spanish children	72	-	-	-	-	-	-	-	-	-	-	-	PU with AT M 12.45 ± 3.7 B 15.2 ± 3.8	-	-	-	
McClelland ⁴²	Ireland	4–15 years children in Ireland	125	-	-	-	-	-	-	-	-	-	-	-	-	Not 0.3 ± 0.39 (4); 0.74 ± 0.58 (6); 2.50 ± 1.27 (10)	-	-	
Alvarez et al. ⁴³	Spain, Madrid	21–80 years clinic population in Spain	271	-	-	21–30 years (0.4 exo ± 2.3) 31–40 years (0.6 exo ± 3.1)	-	-	21–30 years (9.5 ± 2.8) 31–40 years (9.6 ± 3.1)	21–30 years (5.2 ± 2.2) 31–40 years (4.8 ± 2.5)	21–30 years (19.3 ± 8.2) 31–40 years (18.2 ± 9.0)	21–30 years (8.2 ± 5.4) 31–40 years (6.3 ± 5.0)	-	-	-	-	-	-	-
Glerow et al. ⁴⁴	Sweden	8–13 years Swedish children	37	-	-	-	-	-	-	-	-	-	-	-	PU 13.5 ± 1.9	-	± 2 D F (6.7 ± 4.4) (5.5 ± 3.9)	-	
Lanca and Rowe ⁴⁵	Portugal	6–14 years Portuguese children	530	60 or better	PU 6.0 ± 0.3	CT 0.1 exo ± 0.6	CT 1.8 exo ± 2.6	9.7 ± 1.9 near	20.2 ± 5.0 near	-	-	-	-	-	-	-	-	-	-

NPC, near point of convergence; PU, push up with accommodative target; MTT, modified Thorington test; LH, lateral heterophoria; VH, vertical heterophoria; CT, cover test; BI, base in; BO, base out; PB, prism bar; AC/A, accommodative convergence over accommodation; AA, amplitude of accommodation; AR, accommodation response; MAF, monocular accommodative facility; BAF, binocular accommodative facility; P, penlight; M, monocular; B, binocular; Grad, gradient method; Calc, calculated method; F, flippers; exo, exophoria; NS, not specified technique; - (hyphen), means not applicable as the specific study did not report values for such parameters.

†, Distance means test was done at 6 m.

‡, Near means test was done at 0.4 m.

vergence facility, fusional vergence reserves and heterophoria. The mean values and standard deviations of these parameters are shown in Tables 5 and 6. Chen and Abidin⁴ found significant differences among different age groups for measures of positive and negative fusional reserve at distance and negative fusional reserve at near. The specific average values of these measures are, however, not reported.

Razavi et al.⁴⁸ investigated normative data for fusional vergence parameters in Iranian adults who were the target group for keratorefractive surgery (Table 5). For Razavi et al.⁴⁸, the selection criteria for normal participants were adults with no significant eye disorders, including high refractive errors with best-corrected visual acuity better than 20/25, stereopsis of more than 60 sec arc and no heterotropia. There was no significant correlation between the age of participants for fusional amplitudes.⁴⁸ Abraham et al.⁶ have investigated for normative data for NPC, accommodation and phoria in an Indian population. They used techniques that have good repeatability and reliability such as a penlight with red and green anaglyph for NPC, minus lens technique for AA and the modified Thorington method for horizontal and vertical phoria at distance and near. Patients with asthenopic symptoms were excluded using a self-administered symptom questionnaire (a shortened version of the Convergence Insufficiency and Reading Study group questionnaire). The participants were categorised into three groups: group 1: aged 10–18 years, group 2: aged 19–27 years and group 3: aged 28–35 years. Data were recorded on the basis of these three groups (Tables 5 and 6).

Hussaindeen et al.⁴⁹ designed the 'Binocular Vision Anomalies and Normative Data' (BAND) study conducted in rural and urban schoolchildren in Tamil Nadu, India. All children underwent an initial screening protocol that involved a series of testing (e.g. visual acuity, external exams, internal exams, refraction and stereopsis assessment). After screening, children with no abnormalities had a comprehensive BV and accommodative assessment. Asymptomatic children who passed the comprehensive BV assessment protocol with no difficulty in any of the procedures were included in the normative data study. Using the above protocol, Hussaindeen et al.⁷ conducted a population-based cross-sectional study in a sample of Indian children and established normative data for some parameters of BV and accommodation. The mean values and standard deviations of the measured parameters (Tables 5 and 6) are compared with the measures of other studies in Asia.

Hashemi et al.⁵⁰ determined normal values of accommodative amplitudes among adolescent high school students in Iran (Table 6) and found that the AA is lower in Iranian teenagers than that calculated with Hofstetter's formula. Yekta et al.⁹ conducted a cross-sectional study in normal young adult Iranian university students to determine binocular and accommodative characteristics and their association with age and gender. Participants with visual acuity of less than 20/25 in each eye, strabismus, pseudo myopia, latent hyperopia, ocular or systemic diseases, using topical or systemic

medications and with stereopsis less than 400 sec arc were excluded. The binocular and accommodative characteristics and their mean values in the studied sample are shown in Tables 5 and 6. Yekta et al.⁹ also presented mean values and standard deviations for each of the parameters measured according to age group. The measures of positive fusional vergence break and recovery at near were higher in women, but exophoria was significantly higher in men. Some parameters, namely, NPC, distance exophoria, distance base-in-recovery and distance base-in-break, increased with age, whilst other parameters, namely, near base-out-break, AA, BAF, MAF and PRA, significantly decreased with age. The study result indicated that age and gender affect certain parameters of vergence and accommodation.

A summary of expected BV parameters from the existing studies in Asia is included below. The norms of stereo acuity for the Asian population with an age range of 18–40 years are estimated to be 45 sec arc – 19.5 sec arc.^{7,48} The push-up NPC break norms for Asian population with an age range of 7–35 years are estimated at 3 cm – 8.87 cm,^{7,9} and the push-up recovery norms for Asian children aged 7–18 years are estimated to be 4 cm – 8 cm.⁷ The standards for distance lateral heterophoria (DLH) for Asians aged 6–35 years are estimated to be 1 Δ esophoria to –3 Δ exophoria.^{4,6,7,9} The standards for NLH for Asians children are estimated at 2 Δ esophoria to 6 Δ exophoria,^{4,6} and for adults, it ranges from 3 Δ esophoria to 10 Δ exophoria.^{6,9} The norms for vergence facility for Asian children are not less than 8 cpm.^{4,7} The expected accommodative response for Asian children aged 6–18 years is estimated at 0.25 D – 0.67 D.^{4,7} This is applicable to children in Malaysia and India. The expected values of MAF for the Asian population aged less than 35 years are estimated at 7 cpm – 17 cpm^{7,9} using 2 D flippers. The expected AC/A ratio for Asian children is estimated at 5/1,^{7,9} the expected estimated range of PRA is 2.16–5.22^{4,9} and that for NRA is 1.75–4.04.^{4,9}

Normative data studies in Africa

The first study in 1988 by Kaimbo et al.⁵¹ investigated AA in patients aged 10–58 years, who consulted the ophthalmic clinic at the University of Kinshasa, Zaire. They used the push-up method and found that AA values decreased with age, and were more notable between 30 and 40 years of age. The AA measures were lower compared with those obtained on white populations in other studies. Other studies^{8,52,53} were 21st-century studies and only one study, that is, Wajuihian,⁸ comprehensively investigated normative data for parameters of accommodation and vergence. The other three studies^{52,53,54} investigated for AA and compared their results with Hofstetter's age-expected norms.

Ovenseri-Ogbomo et al.⁵² conducted a study in healthy Ghanaian schoolchildren (children with no refractive error and ocular abnormality at initial examination) aged 8–14 years and found a mean AA value of 16.86 D ± 3.07 D using Donder's push-up method. The AA values showed a characteristic decline with increasing age.⁵² Among 688 normal (no refractive errors or with ±0.25 D of spherical

TABLE 5: Normative data for vergence parameters in Asia.

Authors	Study setting	Population (age)	Sample size	Stereo acuity	NPC (break)	NPC (recovery)	Distance lateral heterophoria	Distance vertical heterophoria	‡Near-lateral heterophoria	‡Near-vertical heterophoria	DNFV (blur)	DNFV (break)	DNFV (recovery)	DPFV (blur)	DPFV (break)	DPFV (recovery)	NNFV (blur)	NNFV (break)	NNFV (recovery)	MPFV (blur)	MPFV (break)	MPFV (recovery)	Vergence facility (cpm)	
Chen and Albidin ⁴	Malaysia (Malay)	6-12 years, Malaysians	60	-	-	-	Maddox Rod 0.28 exo ± 0.82	-	Howell card 1.84 exo ± 3.9	-	-	-	-	-	-	-	-	-	-	-	-	-	PB 19.40 ± 9.38 PB 14.60 ± 5.00 RP 12.4 ± 6.15	20.18 ± 5.00
Razavi et al. ⁸⁸	Iran (Khatam-Al-Anbilia hospital)	20-40 years, Iranians	111	Titmus stereo test 37.5 ± 18 sec arc	-	-	-	-	-	RP 3.78 ± 1.69	RP 7.44 ± 3.03	RP 4.78 ± 2.4	RP 5.08 ± 2.64	RP 10.88 ± 4.61	RP 7.85 ± 4.4	RP 13.86 ± 4.98	RP 10.55 ± 4.52	RP 13.86 ± 4.98	RP 10.55 ± 4.52	RP 9.21 ± 4.12	RP 15.53 ± 6.24	RP 12.4 ± 6.15	-	
Abraham et al. ⁶	India	10-35 years, Indians	150	-	PLRG Objective -10-18 years: 6.3 ± 2.8; 19-27 years: 8 ± 3.39; 28-35 years: 8.33 ± 3.16	PLRG subjective -10-18 years: 8.63 ± 3.23; 19-27 years: 10.11 ± 3.2; 28-35 years: 10.11 ± 3.2; ± 1.75	MTT 10-18 years: 0 ± 1.2; 19-27 years: 0.55 exo ± 2.12; 28-35 years: 0.4 exo ± 1.75	MTT 10-18 years: 0.17 hyper ± 0.74; 19-27 years: 0.06 hypo ± 0.36; 28-35 years: 0.08 hypo ± 0.36	MTT 10-18 years: 1.2 exo ± 2.63; 19-27 years: 0.65 exo ± 3.58; 28-35 years: 2.17 exo ± 4.45	MTT 10-18 years: 1.06; 19-27 years: 0.04 ± 0.65; 28-35 years: 0.1 hypo ± 0.58	-	-	-	-	-	-	-	-	-	-	-	-	-	
Hussaindeen et al. ⁷	India (Tamil Nadu)	7-18 years, Indian schoolchildren	936	Randot stereo test 40 ± 15 (arc/sec)	PU with AT 3 cm ± 3 cm FL with red filter 7 cm ± 5 cm	PU with AT 4 cm ± 4 cm; PLRG 10 cm ± 7 cm	MTT 0.02 eso ± 1	MTT 0 ± 0.5	MTT 0.4 exo ± 2	MTT 0 ± 0.5	PB 8 ± 2	PB 6 ± 2	PB 12 ± 7	PB 17 ± 8	PB 12 ± 7	PB 15 ± 4	PB 11 ± 4	PB 26 ± 10	PB 21 ± 10	PB 26 ± 10	PB 21 ± 10	PB 26 ± 10	12BO/3 BI FP, 12 ± 4 (7-12 years), 14 ± 4 (13-17 years)	
Yekta et al. ⁹	Iran (Mashhad University)	18-35 years, Iranian students	382	-	PU with AT 5.27 cm ± 3.60 cm	CT DP 5.02 exo ± 4.74; AP 0.55 base-in ± 1.02 (MU)	CT 1.15 exo ± 2.04	-	-	-	PB 8.82 ± 2.82	PB 6.05 ± 2.51	PB 13.79 ± 5.56	PB 10.61 ± 4.2	PB 20.64 ± 7.47	PB 13.79 ± 5.56	PB 8.65 ± 4.97	PB 13.97 ± 3.79	PB 8.65 ± 4.97	PB 13.97 ± 3.79	PB 21.36 ± 6.25	PB 31.44 ± 6.73	PB 22.85 ± 6.04	

NPC, near point of convergence; PLRG, penlight with red green lens; PB, prism bar; PU, push up; AT, accommodative target; MTT, modified Thorington test; DNFV, distance negative fusional vergence; DPFV, distance positive fusional vergence; NNFV, near negative fusional vergence; MPFV, near positive fusional vergence; FL, fixation light; CT, cover test; RP, rotary prisms; PB, prism bar; exo, exophoria; eso, esophoria; hypo, hypophoria; (hypothen); means not applicable as the specific study did not report values for such parameters; DP, dissociated phoria; AP, associated phoria; MU, Mallett unit; FP, flipper prisms.

‡. Distance means the test was done at 6 m.

‡. Near means the test was done at 0.4 m.

ametropia, and no ocular diseases) Nigerian schoolchildren, aged 6–16 years, Oveneri-Ogbomo and Oduntan⁵³ found the Donder's push-up mean AA to be 15.88 D \pm 3.46 D. The results of these two similar studies^{52,53} were significantly higher than the minimum and average age-expected norms calculated using Hofstetter's equation.

Abu et al.⁵⁴ compared different techniques for measuring AA among 352 normal (participants with best-corrected visual acuity of 0.00 logMAR or better in each eye at distance and near with MEM within +0.25 to +0.75, no strabismus, no amblyopia, no aphakia and no ocular disease) Ghanaian non-presbyopes aged 10–39 years. They found that Hofstetter's formulae could be used to predict AA using the push-up and modified push-up methods. In their study, they indicated the mean AA value for each technique used for the following age groups: 10–19 years, 20–29 years and 30–39 years. The

push-up technique recorded the highest mean amplitude of 12.50 D \pm 3.30 D, modified dynamic retinoscopy was 11.60 D \pm 3.19 D, push-down was 10.10 D \pm 2.60 D and the minus lens method was 7.91 D \pm 1.71 D.

In 1056 black South African junior high school students aged 13–18 years, Wajuihian⁸ determined normative data for accommodative, vergence and stereo acuity measures. His research design involved random sampling of students, and each parameter was measured thrice by only one examiner, with average values recorded as norms. Participants had no suppression, strabismus, nystagmus, ocular motility problems, ocular diseases and systemic disease and were not on any systemic medications that could affect near visual function. The specific tests performed, the techniques and instruments used and the normative data derived are summarised in Table 7.

TABLE 6: Normative data for accommodative parameters in Asia.

Authors	Country	Study setting	Population	Sample size	AA (D)	AR (D)	MAF (cpm)	BAF (cpm)	NRA	PRA	AC/A
Kim ⁴⁶	Korea	-	6–70 years Koreans	490	6–10 years: range 16.25–11.50; median 14.50; mean 14.55 11–15 years: range 16.25–11.00; median 12.50; mean 12.36 16–20 years: range 13.50–8.75; median 10.50; mean 10.75 21–25 years: range 12.00–5.50; median 9.00; mean 8.86	-	-	-	-	-	-
Chen and Abidin ⁴	Malaysia	Malay	6–12 years Malaysians	60	-	MEM 0.4 \pm 0.27	\pm 1.5 D F 20.1 \pm 6.4	\pm 1.5 D F 19.8 \pm 6.3	3.25 \pm 0.79	-3.90 \pm 1.32	-
Razavi et al. ⁴⁸	Iran	Khatam-Al-Anbia Hospital	20–40 years Iranians	111	-	-	-	-	-	-	-
Abraham et al. ⁶	India	-	10–35 years Indians	150	MLB B 10–18 years: 9.96 \pm 1.73; 19–27 years: 8.76 \pm 1.47; 28–35 years: 7.34 \pm 1.34 M 10–18 years: 10.02 \pm 1.72; 19–27 years: 9.04 \pm 1.47; 28–35 years: 7.34 \pm 1.44	-	-	-	-	-	-
Hussaindeen et al. ⁷	India	Tamil Nadu	7–18 years Indian schoolchildren	936	NS B 7–10 years: 13 \pm 3; 11–17 years: 11 \pm 3 M 7–10 years: 13 \pm 3; 11–17 years: 11 \pm 2	MEM 0.4 \pm 0.2 (7–12 years)	\pm 2 D F 7–12 years: 11 \pm 4 13–17 years: 14 \pm 5	\pm 2 D F 10 \pm 4 (7–12 years) 14 \pm 5 (13–17 years)	-	-	Grad 5.4 \pm 0.6
Hashemi et al. ⁵⁰	Iran	Kermanshah,	11–17 years Iranian high schoolchildren	901	NS Overall 11.53 \pm 3.02 range: 5.00–28.50 11 years: 15.33 17 years: 10.40 Boys: 10.09 \pm 2.48 Girls: 11.65 \pm 3.03	-	-	-	-	-	-
Yekta et al. ⁹	Iran	Mashhad University	18–35 years university students in Iran	382	PU with AT 11.14 \pm 2.6	-	\pm 2 D F 11.33 \pm 5.58	\pm 2 D F 8.84 \pm 4.47	2.08 \pm 0.33	-2.92 \pm 0.76	NS 4.66 \pm 1.59

AA, amplitude of accommodation; MLB, minus-lens-to blur technique; M, monocular; B, binocular; PU, push-up technique; AT, accommodative target; AR, accommodation response; MAF, monocular accommodative facility; BAF, binocular accommodative facility; MEM, monocular estimation method; D, dioptres; cpm, cycles per minutes; NRA, negative relative accommodation; PRA, positive relative accommodation; F, flipper lens; AC/A, accommodative convergence to accommodation; Grad, gradient method; NS, not specified technique; -, hyphen: means not applicable as the specific study did not report values for such parameters.

TABLE 7: Binocular vision parameters and normative data from Wajuihian.⁸

BV test	Technique	Instrument	Normative data
Stereopsis	Randot stereo test	Randot stereo plates	43.9 ± 25.2 sec arc
NPC (break)	PU using AT	RAF rule using VLT	6.9 cm ± 2.9 cm
NPC (recovery)	PU using AT	RAF rule using VLT	9.5 cm ± 3.5 cm
DLH (pd)	Von Graefe technique	phoropter	0.09 exo ± 1.7
DVH (pd)	Von Graefe technique	phoropter	0.03 ± 0.3
NLH (pd)	Von Graefe technique	phoropter	1.78 exo ± 4.2
NVH (pd)	Von Graefe technique	phoropter	0.03 ± 0.4
NNFV (break)	Step vergence	Horizontal PB	17.4 ± 5.5
NNFV (recovery)	Step vergence	Horizontal PB	12.5 ± 4.2
NPFV (break)	Step vergence	Horizontal PB	25.4 ± 9.2
NPFV (recovery)	Step vergence	Horizontal PB	17.5 ± 6.8
AA	Donder's PU	RAF near point rule	15.6 D ± 3.2 D
pAR	MEM technique	Streak retinoscope and trail lens	0.6 D ± 0.2 D
MAF	Flipper lenses	±2 D flipper lens	8.7 cpm ± 3.4 cpm
BAF	Flipper lenses	±2 D flipper lens	8.8 cpm ± 3.5 cpm
NRA	-	Phoropter	2.17 ± 0.48
PRA	-	Phoropter	-2.44 ± 0.71

NPC, near point of convergence; PU, push-up technique; AT, accommodative target; RAF, Royal Air Force; VLT, vertical line target; DLH, distance lateral heterophoria; DVH, distance vertical heterophoria; NLH, near-lateral heterophoria; NVH, near-vertical heterophoria; pd, prism dioptres; exo, exophoria; NNFV, near negative fusional vergence; PB, prism bar; NPFV, near positive fusional vergence; AA, amplitude of accommodation; AR, accommodation response; MEM, monocular estimated method; MAF, monocular accommodative facility; BAF, binocular accommodative facility; NRA, negative relative accommodation; PRA, positive relative accommodation.

As illustrated above, five normative data studies were conducted among Africans, four of which investigated only AA; hence, a critical comparison between data could only be conducted using AA values. The push-up AA test value by Abu et al.⁵⁴ (mean age: 14.2 ± 2.7 years) was 14.25 D ± 3.33 D, that of Ovenseri-Ogbomo et al.⁵² (mean age: 11.11 ± 1.9 years) was 16.86 D ± 3.07 D and that of Wajuihian⁸ (mean age: 15.8 ± 1.58 years) was 15.6 D ± 3.19 D. Even though the Abu et al.⁵⁴ and Ovenseri et al.⁵² studies were conducted among Ghanaians at a similar location, difference in AA results could be attributed to age differences. With AA increasing with decreasing age, it was expected that the values found by Abu et al.⁵⁴ would be higher than those by Wajuihian,⁸ but this was not the case. In the studies conducted by Ovenseri-Ogbomo et al.⁵² and Wajuihian,⁸ even though age ranges were different, mean AA values were the same. This indicates that AA values could be different between two different populations; it could also be possible that differences in methodologies (sample size and criteria for selection of normal participants) may have influenced inconsistencies in results. Apart from AA values, which are considered to be different in African populations, the data for BV parameters by Wajuihian⁸ may serve as current standards for black African populations.

Discussion

Comparing normative data across continents

Comparing the average values and range of normative data of studies conducted in similar age groups, the following findings and conclusions are made from the summary normative consensus from different continents. The average

push-up NPC break is comparable between African (6.9 cm) and European children (6.4 cm); the average push-up NPC break is slightly lower for wider age range of American children and adults (5 cm) compared with a wider age range of Asian children and adults (6 cm). The range of push-up NPC recovery is, however, higher in African children (6 cm – 13 cm) than in Asian children (4 cm – 8 cm). The expected range for DLH in Americans is comparable with that of Asians (1 Δ esophoria to 3 Δ exophoria), slightly different from Africans (2 Δ esophoria to 2 Δ exophoria) but lower in range than Europeans (5 Δ esophoria to 1 Δ exophoria). The expected range values for NLH are different for different continents, being orthophoria to 6 Δ exophoria for Americans, orthophoria to 4 Δ exophoria for European children and comparable between Asian and African children (2 Δ esophoria to 6 Δ exophoria). It could be seen that the maximum NLH does not exceed 6 Δ exophoria, being comparable for Americans, Asians and Africans. The expected range of stereo acuity for African children is wider (43.9 sec arc ± 25.2 sec arc) compared with Europeans (60 sec arc or better) than Asians (45 sec arc – 19.5 sec arc).

The expected average MAF is higher for European children (11 cpm) as compared to African children (8.7 cpm), who have a lower average than American children (6.5 cpm). The expected average BAF measures in European and African children are comparable (9 cpm); however, it is wider in range for Africans (standard deviation [SD] ±3.5). The norms for vergence facility for Americans are higher (15 cpm ± 3 cpm) as compared to Asian children (> 8 cpm); however, the data from America were derived from a wider age range comprising children and adults. The range for accommodative response (0.25–0.75) is comparable among Americans, Asians, Europeans and Africans. It is, however, slightly higher for Europeans by approximately 1 D. The range of NRA is greater in Asian populations (1.75 ± 4), compared with Americans (2.00 ± 0.5) and Africans (2.17 ± 0.48). The expected range of PRA is wider for the Asian population (–2.16 to –5.22), and comparable between the American population (–2.37 ± 1.00) and African population (–2.44 ± 0.71). The expected gradient AC/A ratio is higher for Asian children (5:1) as compared to European children (1.9 ± 0.54:1). There is a lack of consensus on AA measures within and across continents. The Hofstetter's equations guide AA data for Americans; however, in other continents it may not be applicable.

Challenges regarding reviewed studies

The most commonly and widely used criteria for NSBV are that of Morgan¹⁹ and Scheiman and Wick,³ whose norms are considered as current standards.^{6,7} The challenge with these standards is that they were derived from the American population and thus are basically applicable to Americans assumed to be in the age range of 6–40 years.^{7,8} The various studies mentioned above were conducted in different populations with different age groups using different techniques; hence, this makes direct comparison of values difficult. Hussaindeen et al.⁷ found certain parameters for

BV, namely, NPC, horizontal phoria, vergence facility, AC/A ratio, AA and AF, in the Indian population to be different compared with similar studies^{3,19,55} carried out in other populations, including ones considered as relevant to the current standards. Yekta et al.⁹ also determined measures that were significantly different from current standards.

Results of some studies were however comparable with previously published norms. Hussaindeen et al.⁷ found that fusional vergence ranges to be clinically comparable with previously published normative data. Gall et al.⁵⁶ and Romano et al.⁵⁷ found data for vergence facility and stereopsis, respectively, to be comparable with existing literature. According to Wajuihian,⁸ there appears to be a consistent trend on reported results of heterophoria even though there are differences in study designs; he found that there was no marked difference between expected values for near phoria, fusional vergence, relative accommodation and accommodative response between his study and other reviewed ones. Copobianco⁵⁸ reported that there is no difference between the NPC break points obtained using an accommodative target or penlight in normal subjects. Hussaindeen et al.⁷ however found in their recent study that there is a significant difference in the break and recovery values of NPC between accommodative target and penlight with a red filter.

There are discrepancies in criteria for defining 'normal' participants in reviewed studies, and this is a challenge. The questions that arise are how normal were the participants and what parameters should be considered to define 'normal' participants to determine expected parameters for the BV system? Hussaindeen et al.⁴⁹ defined good criteria for identifying normal participants to investigate for expected BV parameters and applied this in their study that sought to investigate for expected data.⁷ These criteria involved conducting a preliminary vision screening to eliminate participants with poor visual acuity, ocular diseases, amblyopia, strabismus, nystagmus and poor stereopsis, and reporting comprehensive accommodative and vergence parameter results for selected participants who expressed no difficulty with these procedures.

Normative data studies require very large sample sizes representative of populations under study, but most studies reviewed here used very small sample sizes; thus, measures are not truly representative of the populations studied. Again, few studies^{39,41,46} recorded medians in addition to mean values and standard deviations. We recommend that new studies report, in addition to mean values and standard deviations, medians and quartile deviations or interquartile ranges to cater or correct for values that are outliers. Data normality was also usually ignored in most of the studies; however, it is important to consider data normality when collecting data. Some of the studies that investigated for expected data for AA found that their findings were different from Hofstetter's age-expected norms.^{38,39,41,44,50,52,53} Hofstetter's recommendation was published way back in the

1950s specifically on American children and may not be applicable to other populations. The challenge with reviewed studies was that most studies^{38,41,50,52,53,54} compared their mean AA values with Hofstetter's average values. Only one study³⁹ compared AA results with Hofstetter's minimum values. It is possible that even though the mean values may be different from Hofstetter's average, the range may still be within Hofstetter's range of maximum and minimum values because of differences in standard deviations. Thus, the authors recommend that future studies compare their minimum and maximum AA range with Hofstetter's minimum and maximum values.

It is still not clear as to whether gender influences the parameters of vergence and accommodation as very few studies^{9,50,59} have investigated gender biases because these affect normative data for visual function parameters. Some studies^{50,59} have reported that females have higher AA than age-matched males. According to other authors⁶⁰, this gender difference is not caused by physiological differences in accommodation but rather because females have shorter arms than males. The shorter arms increase habitual accommodative demand for near work in females. As some BV parameters could be different at far and near, most studies investigated these parameters at far and near, whilst only one study⁴³ investigated and reported for heterophoria and fusional vergence parameters at distance only.

Measures for classifying vergence accommodative dysfunctions

The complicated nature of the accommodative and vergence system makes it inadequate to differentially diagnose such anomalies using only single parameters referred to as clinical signs. Correlated clinical signs or visual function parameters that form a syndrome for each anomaly best define the disorders of accommodation and vergence.^{3,8,19} The most common clinical signs include NPC, heterophoria, fusional vergence amplitudes, accommodative amplitudes, accommodative facility, accommodative lag, relative accommodation and stereo acuity.³ The visual parameters or clinical signs used to differentially diagnose anomalies of the vergence system include measures for fusional vergence amplitude at near and far, horizontal and vertical heterophorias at near and far, vergence facility and NPC.¹⁰ Amplitude of accommodation, accommodative response (lag or lead) and monocular accommodative facility are used to characterise the accommodative system.⁵ To evaluate interaction between the vergence system and the accommodative system, visual parameters, namely, NRA, PRA, BAF, stimulus AC/A ratio and stereo acuity, are used.¹⁰ Few studies^{3,4,5,7,8,19} have extensively investigated expected measures for most of the visual function parameters of vergence and accommodation; most studies reviewed have investigated specific visual function parameters only. None of the studies reviewed have reported on vertical fusional vergence reserves and a few have reported on vertical phorias.^{3,6,7} We recommend new normative data studies to include measures for these parameters that are not well specified in the literature. Razavi et al.⁴⁸ in their study

reported measures for negative fusional vergence blur at distance (3.78 Δ), which could possibly be because of the fact that the eyes of participants were not completely relaxed for distance with best refractive correction.

Some factors or guidelines should be considered in performing accurate visual function testing for certain parameters so as to achieve reliable and repeatable results. Heterophoria measures cannot be considered in isolation as they cannot predict symptoms.^{3,61} These measurements are only useful when compared with fusional vergence measures, which determine whether it (the demand) is compensated or decompensated using Sheard's criteria.^{3,61} One factor that greatly influences measures for fusional vergence, and must be controlled, is suppression.⁶² Most studies in the literature did not control for suppression during fusional vergence measurements. Wajuihian,⁸ however, screened for suppression with the Worth Four-Dot test before taking fusional vergence measurements and recommended that it was more appropriate to measure fusional vergence with a suppression control in place. If suppression is not controlled, it may result in high break values because the break is not detected until the stimulus is outside the suppression zone.⁶² In controlling for suppression, the test is stopped if the suppression is detected, resulting in lower values for break.

One study reported that NPC is dependent on age, with younger ones having worse NPC than adults.⁹ There is thus a need to document expected NPC results based on age.^{8,63} During NPC testing, the patient's convergence ability is determined and all three aspects of convergence – namely, fusional, proximal and accommodative convergence – are used. The main targets for NPC are the accommodative target and light source but they have their limitations and advantages.⁷ The accommodative target may not be ideal in cases of reduced AA.⁷ However, it produces more accurate NPC measurements and gives less variability.^{35,64} A light source target may cause accommodative vergence to fluctuate, possibly giving inconsistent readings because the target is a diffused low spatial frequency source.³⁵ However, measuring NPC with a red lens may reduce the effect of voluntary convergence. It is recommended that an accommodative target should be used first because it provides more accurate readings.⁶⁴ In cases where the results from an accommodative target are borderline, or there are signs and symptoms indicative of convergence insufficiency (CI), the NPC could be repeated using a penlight target with the patient wearing red-green filters.^{7,8} Studies have established that using a penlight target with red-green anaglyph is a more sensitive test for diagnosing convergence insufficiency.^{57,64}

Most studies measured AA using the push-up technique.⁸ The minus-lens-to-blur technique, however, has been reported to underestimate AA, whilst the push-up technique tends to overestimate AA.⁸ It is recommended that future studies must investigate for normative data using both push-up technique and minus-lens-to-blur technique. The accommodative facility measure is relevant to diagnose various accommodative anomalies.³ According to Wajuihian⁸

and others, it is recommended that suppression controls are used in measuring BAF even though some studies normally use the Worth Four-Dot test to screen for suppression as was performed in their study. According to Wajuihian,⁸ expected data for accommodative response across studies seem to be the most consistent accommodative measure and this may be because the test is an objective one. The relative accommodation tests are influenced by changes in refraction and indirectly measure the vergence system.³ Lastly, refractive errors, such as anisometropia, affect stereo acuity thresholds and thus must be corrected before checking stereo acuity.^{8,65} This is because anisometropia presents with aniseikonia and retinal disparities, and there is more fovea suppression in defocused eyes.⁶⁵

Conclusion

Across the globe, most of the studies on this topic have been conducted in America, followed by Europe and Asia, with few studies conducted in Africa. Recent studies have investigated most visual function parameters for both accommodation and vergence. The reviewed normative data were determined for specific populations and age groups, and most of the studies have used different methodologies or testing. According to Hussaindeen et al.,⁷ 'to optimise the sensitivity and specificity of diagnosis, ethnicity-specific cut-off values for BV parameters are mandatory'. Each of the expected values reviewed must be applied only to the population of the study. It was expected that studies that recorded different normative values^{7,66,67} may attribute their differences to variations in population, race or ethnicity rather than to methodologies and techniques used. Different study designs and mostly smaller samples in reviewed studies make it difficult to attribute differences in normative data in different studies than to differences in the population used or differences in methodology and techniques.

Again with limited studies and data in and across continents, it is difficult to draw a global consensus on these parameters of NSBV. We recommend large population-based comprehensive normative data studies (targeting parameters of both accommodation and vergence) using most reliable and repeatable, objective and subjective techniques with good methodology in different populations of each continent to clarify these differences or otherwise. In selecting normal participants, we recommend Hussaindeen et al.'s⁴⁹ criteria with slight modifications, which include administering a reliable and validated asthenopic symptom questionnaire to select asymptomatic participants first before preliminary vision screening on asymptomatic participants. We also recommend including a suppression test such as the Worth Four-Dot test in preliminary vision screening to exclude participants with suppression and checking for suppression during fusional vergence and BAF measurements. Populations at risk, such as school-going children, should be the first point of consideration and authors must consider comparing these parameters among genders, as only one study⁹ has determined that gender affects these parameters. A few studies have suggested contrary results for gender.

The authors did not find any normative data study for parameters of accommodation and vergence among any population in Oceania; again, few studies were conducted on the African continent, with only one documenting expected data for both parameters of accommodation and vergence. Thus, we recommend such studies to be conducted urgently to document data for different populations in Oceania and Africa. The main limitation with normative data studies is the difficulty in determining as to what extent these population means could be applied to a single individual in the clinical environment.^{20,29} In spite of this major limitation,^{20,29} these expected values (mean values with standard deviations, medians and quartile deviations) should be used as guidelines for BV case analysis in clinics especially as anomalies are interpreted as syndromes,⁸ with emphasis on the presence of asthenopia.

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Authors' contributions

C.D.T. was the primary author. V.R.M. supervised C.D.T.'s PhD studies, from which this review manuscript was drafted. S.B.B.-K. was the co-supervisor of C.D.T.'s PhD studies and contributed enormously in editing this manuscript.

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Data availability statement

Data sharing is not applicable to this article.

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